AN INTRODUCTION TO

MAPWORK

AND

PRACTICAL GEOGRAPHY

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BY

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PREFACE

This book is designed to provide an introductory course in map reading and practical geography suitable for use in the upper forms of schools and in first year University classes. Care has been taken to include all that is required in the subject for the various General Certificate of Education examinations at Advanced Level, including Special Papers.

In this edition Chapters III to VI have been rewritten by Commander D. H. Fryer, O.B.E., R.N. (Retd), formerly Reader in Surveying, University of Durham, and some minor revisions have been made elsewhere.

The scope of the book will be apparent from the table of contents. Map making is considered first, in chapters which include some elementary aspects of surveying. The problem of map making is approached in a clear manner, so that students will realise how survey work gives the data for the map.

Types of map are then described. Among the Ordnance Survey Maps and Plans are Land Utilisation and Geological Maps. Parts of these and portions of actual 1″, 2½″, 6″, and 25″ Ordnance Survey Maps are included and interpreted. Map reading and interpretation are treated from the point of view of both physical features and indications of human settlement and land use.

Aerial photography is now used a great deal as an aid to map construction and examples of the methods used are described and illustrated. The weather map is dealt with in some detail and examples are reproduced and discussed.

The book explains in Part III why particular map projections are selected for particular purposes. Simple graphical and trigonometrical methods for constructing important projections are carefully explained.

Many useful questions and exercises are included in the book. These have been carefully selected and grouped into sections. Some of the mapwork exercises are reproduced from actual examination questions, and, for permission to include these, thanks are due to the Senate of the University of London and to the Local Examinations Syndicate of the University of Cambridge. They form excellent groundwork for map analysis exercises, and being based on Ordnance Maps are more concrete than "manufactured" examples. Numerous original questions are set on the Ordnance Maps included in this book, and most of them can be applied to other Ordnance Maps. There are also more advanced exercises, which are mainly designed to emphasise the application of surveying methods to mapwork.

Thanks are tendered to the Directors of the Ordnance Survey, the Geological Survey, and the Meteorological Office, as well as to the Controller of H.M. Stationery Office, for permission to reproduce certain maps and diagrams, including Figs. 135 and 164, etc., to Messrs J. H. Steward, Ltd, for the loan of blocks for Figs. 9, 10, 20, 30, and 31, and to the Durham University Excavation Committee for permission to reproduce Figs. 5, 21, and 26 from their *Surveying for Archaeologists*. Acknowledgment is made to Messrs George Routledge, Ltd, for permission to use some diagrams from Mr Bygott's *Eastern England*. In the text, specific reference is made to such diagrams and to those reproduced by permission of the various authorities noted above.

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INTRODUCTION TO
MAPWORK AND PRACTICAL GEOGRAPHY

PART I—MAP MAKING AND TYPES OF MAP

CHAPTER I

INTRODUCTION

1. PROBLEMS OF MAP MAKING

All maps are representations on a plane surface of some part of the earth. On globes which represent the earth, distances and the relative position of places are reckoned with respect to certain lines known as parallels of latitude and meridians of longitude. (See Chapter XVII for explanation of latitude and longitude.) On the globe, such lines are circles. At the expense of sacrificing truth to a greater or lesser degree, it is possible to project them on to a plane surface, and a network known as a **graticule** or **projection** is the result. Such network is the basis of properly drawn maps, but there are many types of network; some of the most important are treated later in Chapters XVII, XVIII, XIX.

The most important problems of *cartography*, which is the science of map making, are:

(1) Selection of a suitable scale, which determines the size of a country on the map compared with its real size.

(2) Choice and construction of a projection.

(3) Cartographic representation, namely what to show and how to show it, particularly (*a*) the facts of physical geography concerning the relief and hydrography, (*b*) the facts of human geography, land use, settlements, and communications. Methods of cartographic representation should be designed to show as much as possible compatible with easy legibility. This is all bound up with the limitation of map representation

due to scale, which is treated in Chapter VIII. A very important aspect of cartographic representation is lettering, which should be designed not only to produce the utmost legibility allowed by the scale, but also to emphasise the relative importance of physical features, towns, and political divisions.

(4) Use of colour, lithographic processes, and printing. Formerly maps were produced entirely in black, but now colour is largely used to show relief, water features, roads, vegetation, etc. Selection of suitable tints to show relief is an intricate matter, and when different colours are used a map is printed from many plates, each requiring a separate printing. Great skill and care are necessary to ensure proper correlation of the various colours and tints, and their correct relation to symbols and names.

In criticising methods of representing facts on a map it is always necessary to consider, bearing in mind the limitations of the scale, what geographical facts should be shown and in what respects the map falls short of an ideal standard. At the end of Chapter XIII are hints for the critical cartographical examination of a map.

2. TYPES OF MAPS AND THEIR STUDY

Ordnance maps is the name applied to various types of British maps produced by the Ordnance Survey, which is manned largely by Royal Engineers, but is under the Ministry of Agriculture, Fisheries, and Food. Its Director is always a distinguished officer of the Royal Engineers. Ordnance maps were first made in the eighteenth century, and were based on surveys by Engineer officers, being intended for military purposes, such as defence against invasion. Chapters VIII-XIII, deal mainly with Ordnance maps, principally topographical ones and the larger-scale plans.

It is obvious that a large-scale map of even a small country would be very inconvenient for general use if printed on a single sheet of paper, and therefore such maps are produced on a series of related sheets, each one of which deals with only part of the whole area. One type of sheets, such as those of the British Ordnance maps, has rectangular bounding sheet-lines not related to the lines of latitude and longitude, so that sheets can generally be fitted together without much inconvenience, though sometimes neighbouring sheets overlap. In another type of sheets the sides are straight,

but the top and bottom are curved, being bounded by curved parallels of latitude, which with the meridians are plotted for each sheet; only a limited number of sheets can be fitted together.

The possibilities and limitations of scale cause maps to fall into various classes, each with distinctive characteristics. The largest-scale maps are sometimes known as **Cadastral maps.** They are really plans. The very large scale allows full detail to be given, such as the boundaries of fields, individual buildings, etc., and therefore these maps are useful for purposes of taxation or to define property in legal documents. The 6 in. and 25 in. to the mile Ordnance series are termed plans.

Topographical maps are large-scale maps founded on precise surveys, and show considerable detail of natural and man-made features. They are not on so large a scale as cadastral maps, and cannot show detailed property boundaries. They are useful to motorists and walkers, to soldiers during manoeuvres and in wartime, and to geographers studying the regional geography of an area in some detail. The topographical maps of the Ordnance Survey, particularly useful to the geographer, are those on a scale of 1 in. and $2\frac{1}{2}$ in., respectively, to the mile, and it is with their study that this book largely deals.

In a study of topographical maps it is necessary to examine the methods of representing relief and drainage, in order to obtain some idea of the physical features depicted. Knowledge of the various methods of representing relief and ability to visualise a three-dimension picture of what they represent is necessary (see Chapter XI). Especially important is ability to read **contours,** namely, lines on the map made up of all points which in the actual country are the same height above sea level. A thorough grounding in some of the elementary principles of physical geography is indispensable if full advantage is to be derived from analysis of physical features shown on the topographical map. Chapter XI explains how the more common physical features appear on a contoured map. Various symbols known as **conventional signs** are used by the cartographer to represent natural features such as marshes and cliffs, man-made features such as roads, railways, buildings. It is necessary to know them and to explain their presence, which can often be done by a consideration of the influence of physical features. Conventional signs are dealt with in Chapter VIII, and their application is often

apparent in the analyses of typical Ordnance maps (Chapter XIII). Much of the study of topographical maps should be devoted to interpretation of land forms and their influence on human geography, such as the distribution and character of settlements and the development of communications.

FOREIGN MAPS.—This book deals essentially with British maps, but after studying these the student may care to examine some foreign maps similar to them in scale and purpose, and to make comparison. Foreign countries which use the metric system find a scale of 1 in. to the mile inconvenient, and for maps corresponding to our one-inch series have adopted a scale of 1 : 50,000, which is approximately 1¼ in. to the mile. Approximately, a scale of 1 : 100,000 corresponds to our half-inch and a scale of 250,000 to our quarter-inch. A scale of 80,000 (nearly ¾ in. to the mile) is used on some maps, especially on a French series. Some foreign maps, particularly the French, 1 : 50,000, show more varied detail than ours, and some show features which do not occur in Britain, as the glaciers of Switzerland.

An important map is the **International map,** which, with the co-operation of various countries, was designed to produce a uniform map of the world, divided into sheets uniform in scale, size, shape, and style of drawing. Hinks' *Maps and Survey* (Chapter IV) has a helpful description and criticism of the International map. Chapter V deals with "The maps of Europe", and Chapter VI with "Other foreign maps"; both chapters give analyses of typical sheets on various scales of the official maps of foreign countries. French, German, and Swiss sheets on the scales noted above will repay study.

ATLAS MAPS.—Atlas maps are on a smaller scale than topographical maps, and generally show details condensed and generalised from such maps. Few atlases have a scale as large as 1 : 1,000,000 (nearly 16 ml. to the inch), but in *The Times Survey Atlas of the World* the maps of France and Germany, each covering several sheets, are on this scale, and the British Isles sheet maps of this atlas are on even a larger scale, namely 1 : 633,600 (10 ml. to the inch). *The Times* atlas maps are much larger than those of the ordinary school atlas. It is a work of reference, and there are a few foreign atlases similar in scope.

To-day the best school atlases, despite their limitations of space and the necessity of keeping the price within a reasonable limit, are compiled on

logical and scientific lines. Maps of the world showing relief, vegetation, climatic data, or ocean currents are shown on projections considered suitable for depicting true shape, areal distribution, etc., and though sometimes improvement could be suggested, a good modern atlas usually shows wise choice of projections. The continents and the larger countries often have a physical map and a political map on opposite pages, drawn on the same graticule and scale, so that the political map can be read in the light of physical factors. Where two such maps are not deemed possible, boundaries, routes, railways, and other political details are usually shown on a colour-layered relief map, and if some overcrowding does result, such a map is better than the purely political one. Some atlases give distributional maps (see p. 155), but these are usually too generalised to be anything more than a broad guide to the location of, say, temperate grassland. It is not easy to make a good distributional map on a small scale—the dot method (see p. 156) is not usually practicable. However, the *Oxford Economic Atlas of the World* gives excellent examples of such maps.

DISTRIBUTIONAL MAPS.—Maps which, with the aid of certain symbols, or shading schemes, show the distribution of crops, stock, or people in a given area are known as **Distributional maps.** Such maps dealing with crops, stock, or minerals are sometimes termed **Commodity maps.** The distribution may show actual figures, generally expressed in round numbers, or may show numbers of stock or people per square mile or per 1,000 acres, or percentage of area under any specified crop. In Chapter XIV the various methods of making distributional maps, with their respective advantages and disadvantages, are discussed.

GEOLOGICAL MAPS.—Some maps show the distribution of different rocks, usually in combination with contours, so that they guide us in interpreting physical features and in tracing their evolution: such maps are called **Geological maps.** They are useful aids in the study of physical geography and often have very practical significance. Geological maps of newly developed colonies, for instance, are very important as guides to the development of mineral wealth and soils.

NATIONAL ATLAS.—The Ordnance Survey have a series of maps entitled the "National Atlas". They are on the scale of 1 : 625,000, or approximately 10 ml. to the inch. Great Britain is covered by two sheets;

(1) Scotland, with that part of England north of Kendal; (2) remainder of England with Wales. The series includes a topographical base map for (1) and (2), and maps covering some particular aspect of geography. Separate maps deal with administrative areas; coal and iron; electricity supply areas; Gas Board areas; gas and coke supply areas; iron and steel; land classification; land utilisation; local accessibility; population changes (1921-31), (1931-9), (1938/9-47) on three separate maps; population changes by migration (1921-31), (1931-9), (1938/9-47) on three separate maps; population density (1931); population of urban areas; railways; rainfall; roads; solid geology, coloured and outline editions; topography; types of farming; and vegetation. A series of historical maps are also published in this series, covering particular periods, *e.g.* Monastic Britain and Ancient Britain.

Most of these maps have been specially prepared under the direction of Dr E. C. Willatts in the Maps Office of the Ministry of Town and Country Planning, and in the Maps Office of the Department of Health for Scotland, but some have been compiled by other departments or research organisations.

The two maps offices have intensively examined a great amount of information, much of it unpublished, and charted the results on large-scale manuscript maps, from which has been drawn the above series of "National Atlas" maps.

WEATHER AND CLIMATE MAPS.—Each day **Weather maps** are prepared for that day by the Meteorological Office in London from data founded on observations made at numerous observing stations. They deal mainly with temperature, pressure, winds, and rainfall, and in addition to showing the general weather conditions of the British Isles and adjacent regions at a specified time, form the basis of a weather forecast for the succeeding twenty-four hours. Various symbols (see p. 174) are given on each weather map to indicate certain aspects of weather. Study of weather maps includes ability to read them and to describe the current weather conditions, as well as to suggest likely developments in the near future. Weather maps dealing with their own local conditions are issued by the larger European countries, the United States of America, Canada, Australia, etc. If a few specimens of any such maps can be obtained, much benefit will result from their study and comparison with the British maps.

Weather maps deal with conditions at a specified instant of time, **Climate maps** with the average weather conditions during a specific period, for instance, a month or a year. The data for weather maps are absolute, that is, conditions which were actually observed at the time in question. Climatic data are generally averages for a considerable number of years or months as the case may be. A map showing January temperatures would be based on the average figures for the Januarys of as many years as possible. A mean annual rainfall map would be based on the average rainfall of many years. A weather map usually shows the various elements of weather on the same map, for instance, temperature, pressure, winds, rainfall. A climatic map is more specialised, that is, there are generally separate maps for temperature, pressure, rainfall, etc. Given a set of such maps for January and July, usually (in the Northern hemisphere) the coldest and hottest months, or better still, for January, July, October, and April, representative of each season, it is possible to build up a generalised description of the climate of a region. Weather may be compared with the news in a daily newspaper, climate with the summary of a year's events.

CHAPTER II

SCALES: THEIR MEANING, USE, AND CONSTRUCTION

1. THE MEANING OF SCALE

Scale has the meaning of a ratio. It signifies the proportion which a length on the map bears to actual distance on the ground. To speak of the scale of one inch to a mile means that if we measure one inch as the distance between, say, two churches shown on the map, this distance would be a mile in the actual country.

It is not possible that the scale of any map should be correct in all directions. The earth is not flat like our map. On a small globe try to paste a tiny piece of paper to cover, say, Denmark. It would probably not pucker and would remain flat. Now try to cover Europe or the Americas with a larger piece of paper. This would show wrinkles and creases, and might require folding to make it fit on the globe. This shows us that small-scale maps of large areas suffer most from errors of scale, and large-scale maps of small areas least, in fact, very little for practical purposes.

Some projections, however, give correct scale in certain directions, as along particular parallels and meridians. On other parts of the map the scale may not be true.

2. USE OF SCALES

In making a map to given scale it is necessary to bear in mind the purpose for which the map is intended, as well as the amount and the character of the detail to be shown. Town plans require a large scale in order to show the outline of buildings. An atlas map designed to show the general distribution of high land and low land need not be on so large a scale.

It is essential that on any plan or map there should be some indication of the scale in order that distances may be easily calculated. There are various ways of indicating scale. In British maps the scale is indicated by one of two common methods.

(1) By direct statement of so many inches to the mile or so many miles to the inch.

(2) By use of a fraction whose numerator, 1, indicates the length on the map, and whose denominator indicates the length in the actual country. Thus the fraction $\frac{1}{63360}$, sometimes written 1 : 63,360, indicates the scale of 1 in. to the mile. There are 63,360 in. in a mile, and the fraction signifies that one inch on the map represents 63,360 in. in the real country. Such a fraction is called the **Representative Fraction.** This method is very useful where a map may be consulted by people outside the country for which it is primarily intended. A Frenchman unfamiliar with English measures might not be very confident in calculating distances from a map which was labelled with a scale of 6 in. to the mile. But tell him that the scale of this map is $\frac{1}{10560}$ and he can use it readily, because this method is employed for his own country's maps. He would not think in English measure, but in metres, with the decimal notation to which he is accustomed. Thus $\frac{1}{10560}$ to a Frenchman would mean 1 cm. to 10,560 cm., etc.

The following simple rules are useful:

(1) *Given the Representative Fraction, to find (a) the number of inches to the mile, (b) the number of miles to the inch.*

(*a*) Divide 63,360 by the denominator of the fraction,

e.g. if R.F. is $\frac{1}{10000}$, then $\frac{63360}{10000} = 6{\cdot}336$ ($6{\cdot}34$ approx.) in. to 1 ml.

(*b*) Divide the denominator of the fraction by 63,360,

e.g. if R.F. is $\frac{1}{316800}$ then $\frac{316800}{63360} = 5$ ml. to 1 in.

(2) *Given the number of miles to the inch, to find the Representative Fraction.*

Multiply 63,360 by the number of miles to the inch in the given scale, and you will have the denominator of the R.F., *e.g.* 4 ml. to the inch

$$= 1 : 63{,}360 \times 4 = \frac{1}{253440} = \text{R.F.}$$

(3) *Given the number of inches to the mile, to find the Representative Fraction.*

Divide 63,360 by the number of inches to the mile in the scale, and you will have the denominator of the R.F.

E.g. If the scale is 4 in. to the mile, denominator of R.F. is

$$\frac{63360}{4} = 15{,}840, \text{ and R.F. is } \frac{1}{15840}.$$

It is convenient to note the following tables:

R.F. FROM SCALE

Scale-Inches to the mile	R.F.
$\frac{1}{4}$	$\frac{1}{253440}$
$\frac{1}{2}$	$\frac{1}{126720}$
1	$\frac{1}{63360}$
6	$\frac{1}{10560}$

SCALE FROM R.F.

R.F.	Scale-Inches to the mile
$\frac{1}{10000}$	6·34 (approx.)
$\frac{1}{50000}$	1·27

R.F.	Scale-Miles to the inch
$\frac{1}{100000}$	1·58
$\frac{1}{250000}$	3·95
$\frac{1}{500000}$	7·89

3. PLAIN SCALES

On maps, in addition to the statement of scale or indication of the Representative Fraction it is convenient to give what is known as a **plain** or **linear scale.** This is merely a line conveniently subdivided so that distances on the map can easily be read from it by using a piece of cotton or dividers. A plain scale should be long enough for measurement to be reckoned from it easily, and it should represent a convenient round number of the unit selected so that subdivision is facilitated.

EXAMPLE

Construct a plain scale for 6 *ml. to the inch.* (See Fig. 1.)

By the given scale 5 in. represents 30 ml., giving six primary divisions. Take another 5 ml. to divide into secondary divisions.

If 5 in. represent 30 ml., we must determine how many inches represent $30 + 5 = 35$ ml., *i.e.* $\frac{35 \times 5}{30} = 5{\cdot}83$ in.

Draw a line *AB*, 5·83 in. long, divide it into seven parts, and subdivide the left-hand side part into five smaller parts of 1 ml. each. The method is as follows:

From A draw AC rather longer than AB and making an angle not more than 30° with AB (a larger angle might lead to inconvenience in drawing). On AC, with dividers, from A mark seven points m, n, etc. (the same number as the required divisions of AB), at equal distances, which may be approximately $\frac{1}{7}$ of AB. Join t, the last point, to B, and from the other points draw lines parallel to tB. These parallel lines cut AB and give the required divisions.

The first division can be subdivided into five equal parts by the following method:

At A erect Ax perpendicular to AB and divide it into four equal parts.

At O erect Oy equal to Ax in length and perpendicular to AB, so that it runs in the opposite direction to Ax. Divide Oy into four equal parts.

Join x to the division on Oy nearest to O. Join y to the division on Ax nearest to A. Join the other two divisions similarly, as shown (Fig. 1). By comparison of the proportional triangles shown in the diagram, it will be seen that AO is now divided into five equal parts. AO may also be divided by the method used for the division of AB.

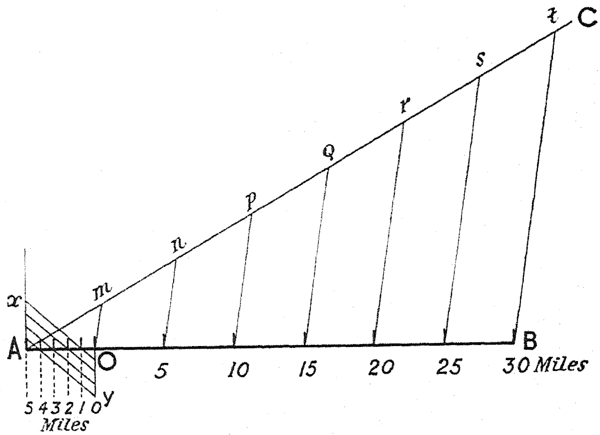

Fig. 1. To Divide a Line, 5·83 In. Long, into 7 Equal Parts to Give a Plain Scale to show 6 Ml. to the Inch.

Some people think a graphical method of drawing a scale unnecessary. If they wished to show, say, 2,100 yd. on a scale of 5 in. to the mile, they would possibly work the sum $\frac{2100 \times 5}{1760} = 5{\cdot}96$, and then make use of a suitable ruler.

A **diagonal scale** is given on some protractors and rulers. Its use will be seen from Fig. 2. When the dividers are in the position xx', it is obvious that the measurement is 1 in. and nine-tenths, *i.e.* 1·9. If the point x were

on the same diagonal, but one space up, it becomes 1·91, two spaces up 1·92, three spaces up 1·93, and so on. When they are in position *yy'*, the measurement is seen to be more than 2·5 in., but less than 2·6 in. The divider point *y* is on the sixth horizontal line from the bottom, hence the measurement is 2·56 in. The distance to represent every 100 yd of the scale noted in the preceding paragraph is 5·96 divided by 21 = 0·28 bottom, hence the measurement is 2·56 in. The distance to represent 100 yd on the scale noted in the preceding paragraph is 5·96 divided by 21, or about 0·28. For this, the divider points are indicated by crosses on the diagram.

Reduction and enlargement of maps will emphasise the significance and the limitations of scales. Not only is less detail possible on a small-scale

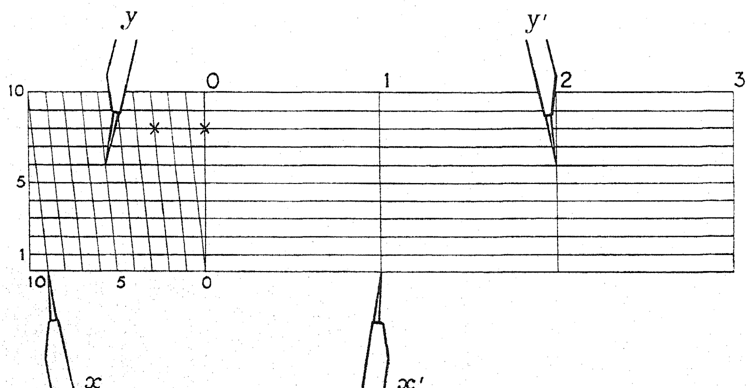

Fig. 2.

map, but the details, notably rivers and roads, must be shown in a very generalised way, and frequently of a size out of proportion to the scale.

To reduce maps to a smaller scale, take the two scales to represent a fraction thus:

$$\frac{\text{New scale}}{\text{Old scale}} = \frac{1}{x}.$$

Divide the original map into squares and draw a new outline with similar squares, the sides of which must be $1/x$ of the original. Sketch in as much detail as possible.

Throughout this chapter the use of the word "scale" has been applied to *horizontal scale*.

EXERCISE 1

SCALES

1. What are the Representative Fractions of the British Ordnance maps on scales respectively 1 in., $\frac{1}{2}$ in., and $\frac{1}{4}$ in. to the mile?

What statements of scale in centimetres to the kilometre correspond to the above-mentioned maps?

2. Which is on the larger scale: the British 1 in. Ordnance map or the French 1 : 50,000 map? Give a brief reasoned answer in support of your statement.

3. Construct suitable scales in centimetres to the kilometre for the maps mentioned in Question 1.

4. Draw suitable scales in inches to the mile and centimetres to the kilometre for the international map (1 : 1,000,000).

5. Find the Representative Fraction for each of the following scales: 5 ml. to 1 in., 5 in. to 1 ml., $\frac{1}{2}$ cm. to 1 km., 2 cm. to 1 km., 5 in. to 1,000 links.

6. Construct a scale of 4 ml. to the inch to show half-miles, and one of 6 in. to the mile to measure 1,000 yd.

7. A racing motorist, travelling at 90 m.p.h., covers a straight length of road between two points, *A* and *B*, in 10 min. If the distance between *A* and *B* measures 5 in. on a map, what is the R.F. of this map? Give a reasoned answer, and construct a scale to show miles.

8. You are given a map, *x*, for some 40 sq. ml., showing the results of careful triangulation and systematic contouring. It is on a rather larger scale than 1 : 63,360 and considerably less than 1 : 10,560. If you have sheets of the 1 in. and 6 in. Ordnance maps of the same country, say how, by using either of these Ordnance maps, you could ascertain the scale of the map *x*. Draw a suitable scale for its showing 1,000 yd. intervals.

9. To construct a time-scale, for, say a map of scale 1 in. to the mile, for a person walking 4 m.p.h., note that 4 in. represent 4 ml. (covered in 1 hr). Draw a line 4 in. long, bisect it and number the centre as "0" and the right-hand end as "30 min." The half of the line to the left of 0 can be divided into three equal parts, each representing 10 min. and numbered (right to left) 10, 20, 30 min.

Discuss the practical value of such a scale, and construct scales to show the distance traversed by an exploring party travelling $2\frac{1}{2}$ m.p.h., using maps of scale 1 : 50,000 and 1 : 63,360.

10. You have three maps respectively on a scale of 1 : 50,000, 1 : 63,360, 1 : 80,000 to represent parts of a region for which a map on a common scale of 1 : 60,000 is to be made. If sides of grid squares on the redrawn map are to be 1 in., what are they on the other maps? Give a reasoned answer.

Draw scales for the new map to show miles and kilometres respectively.

CHAPTER III

CONTOURS AND CONTOURING

1. VERTICAL INTERVAL AND HORIZONTAL EQUIVALENT

CONTOURS.—Generally speaking, the most convenient way of representing heights and slopes on a map is by means of contour lines; these are continuous lines drawn through all points on the map which have the same altitude above mean sea level. They represent the line of intersection between a horizontal plane, at some specified height, and the surface of the country; thus complete contours, representing as they do the perimeter of one horizontal plane, are closed curves which cannot cut into another contour, the perimeter of a different horizontal plane. However, on a map of steep ground the contours will tend to merge into each other and on a cliff face where the perimeter of one horizontal plane is, in fact, vertically above that of another, the contours drawn on the map must be superimposed on one another and so merge into one line. (This logical representation tends to mislead the eye and fails to give the map reader a true impression of steepness. Consequently it is customary to add some additional indication in the form of cliff shading—short vertical lines drawn perpendicular to the contours. See frontispiece.)

For accurate contouring the absolute heights of very many points on the ground must be known (except in the case of mapping from air photographs, see Chapter VII, where fewer absolute heights are required). In sketch or exploratory surveys frequently so few absolute heights have been determined that the surveyor is not justified in drawing full contours and has to be content with **form lines.** These are approximate contours which are sketched in while the survey is being made; they serve to show the general shape of the land between such absolute heights as have been determined. To emphasise their approximate character they are usually shown in broken lines.

The **Vertical Interval** (V.I.) is the height difference between successive contours, while the **Horizontal Equivalent** (H.E.) is the horizontal distance between them.

To depict the shape of very flat ground, obviously, a small V.I. is required; while on very steep ground a larger one is more desirable. Nevertheless, on most national maps a definite policy is laid down relating the V.I. to the scale of the map, *e.g.* the Ordnance Survey uses a 50 ft V.I. on their 1 in. to the mile series and a 25 ft V.I. on the 1/25,000 sheets.

2. THE SCALE OF SLOPES

There is a definite relationship between the H.E. and the V.I. which varies according to the slope of the ground. If $D°$ is the slope of the ground referred to the horizontal, $\frac{\text{V.I.}}{\text{H.E.}} = \text{tangent of } D°$ or, $\text{H.E.} = \frac{\text{V.I.}}{\tan. D°}$. However, as it is customary to give the H.E. in yards, while the V.I. is nearly always given in feet, a more rough and ready rule may be used to construct a **scale of slopes.** The base of a right-angled triangle with an angle of 1° opposite the perpendicular is 57·3 times the length of the perpendicular, from which it can be seen that for a V.I. of 1 ft the H.E. is 19·1 yd. If for 19·1 we substitute a round number of 20 we can say that $\text{H.E.} = \frac{20 \times \text{V.I.}}{D°}$ and this is roughly true for slopes up to 20°.

Thus for a V.I. of 100 ft:—

$$\text{For } 1° \text{ of slope} \quad \text{H.E.} = \frac{20 \times 100}{1} = 2{,}000 \text{ yd,}$$

$$\text{,,} \quad 2° \quad \text{,,} \quad \text{,,} \quad \text{H.E.} = \frac{20 \times 100}{2} = 1{,}000 \text{ yd.}$$

Up to 10° of slope the table for a V.I. of 100 ft is:—

Slope	H.E.	Slope	H.E.	Slope	H.E.
½°	4,000 yd	3°	667 yd	6°	333 yd
1°	2,000 ,,	3½°	571 ,,	7°	286 ,,
1½°	1,333 ,,	4°	500 ,,	8°	250 ,,
2°	1,000 ,,	4½°	444 ,,	9°	222 ,,
2½°	800 ,,	5°	400 ,,	10°	200 ,,

For a V.I. of 50 ft these H.E.s are halved and for a V.I. of 25 ft are halved again.

Scales of slope may be constructed but, as can be seen from the tabulation above, if constructed for any scale of map smaller than 6 in. to one mile, the graduations are very close together once a slope of 5° is exceeded.

3. INSTRUMENTS USED TO DETERMINE HEIGHTS

When making a topographical map it is necessary to determine a framework of heights as a control for contouring. Some of these heights will be determined during the triangulation (see Chap. IV) but many others will

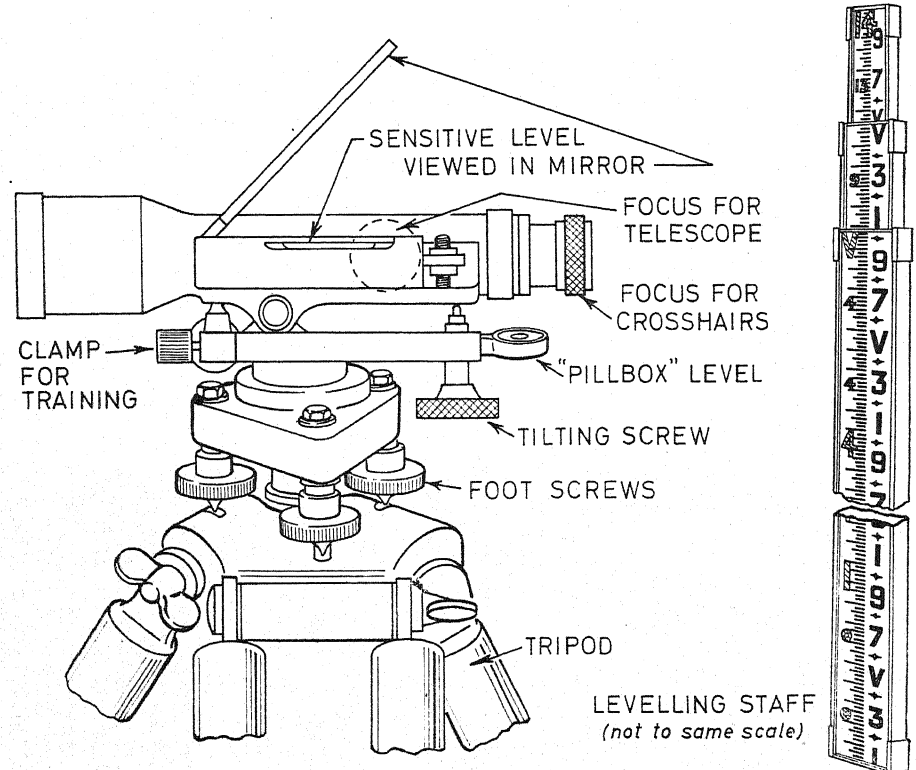

Fig. 3. Level and Staff.

be required and these may be obtained directly by the **spirit level** or **aneroid barometer** or indirectly by the process of trigonometrical levelling, using a **theodolite** or **clinometer.**

For the height control of national surveys precise instruments are used by experienced surveyors and a very high order of accuracy achieved,

errors of less than 0·025 ft $\sqrt{D \text{ miles}}$ (*i.e.* 3 in. for a levelled line 100 miles long) are incurred with the spirit level and 0·35 ft $\sqrt{D \text{ miles}}$ (*i.e.* $3\frac{1}{2}$ ft for levelling along a line 100 miles long) when using a theodolite for trigonometrical levelling. For topographical work and using less precise instruments the order of accuracy will, of course, be considerably less.

THE SPIRIT LEVEL.—Many different patterns of this instrument are used by surveyors but in essentials all are the same and consist of a telescope fitted with cross-hairs, attached to a spirit level, the whole being mounted on a tripod and free to rotate in a horizontal plane about a vertical axis. The level is used in conjunction with a levelling staff, 10 to 16 ft long, which is usually graduated in feet, subdivided into tenths and hundredths (see Fig. 3).

To use the spirit level. Set up the level on firm ground, at L_1 in Fig. 4*a*, so that the top of the tripod is nearly horizontal; tread the feet firmly into the ground by means of the foot steps placed at the bottom of each leg. Now turn the appropriate foot screw until the telescope is approximately level. In most instruments a small "pill box" level will show when this has been achieved. An assistant, the staff holder, next holds the staff vertically on a mark, A, of known height. The observer directs the level telescope on to the staff and focuses the telescope—this is a double operation, the eyepiece is turned until the cross-hairs, inside the telescope, are in focus, and then the main focusing screw is turned until the staff can be read clearly; (it is seldom necessary to alter the focus on the cross-hairs, but a slight re-focus on the staff is needed for every new staff position). Finally, before reading the graduation of the staff cut by the horizontal cross-hair, the observer ensures that the main, sensitive bubble is in the middle of its level tube by moving the tilting screw slightly. The reading is then made, say x ft. This means that the line of sight, the line of collimation, of the telescope is x ft above the level of A. The staff is now moved to B, so situated that $LB = LA$. The telescope is rotated to sight on to the staff in this new position, the focus is adjusted and the sensitive bubble centred in its tube by the tilting screw, if necessary, and the reading made, say y ft, i.e. B is y ft below the line of collimation and the difference of height between A and B is $(x - y)$ ft. The first reading was a "back sight" and the second a "fore sight" and the difference of height is given by "back minus fore"; if this is positive the fore position is the higher, if negative, the back position

is the higher. The level can now be moved to L_2 and the whole process repeated, and thence to L_3, L_4, etc. In this leap-frog movement the staff and the level must never be off the ground together, one or other must always be on the ground and for the actual reading, of course, both must be.

Fig. 4*b* shows the reason for keeping, during any one "set-up" of the level, the back and the fore staff positions at the same horizontal distance from the level. The line *aLb* is the line of equal levels drawn parallel to the earth through *L*; owing to the curvature of the earth the true horizontal

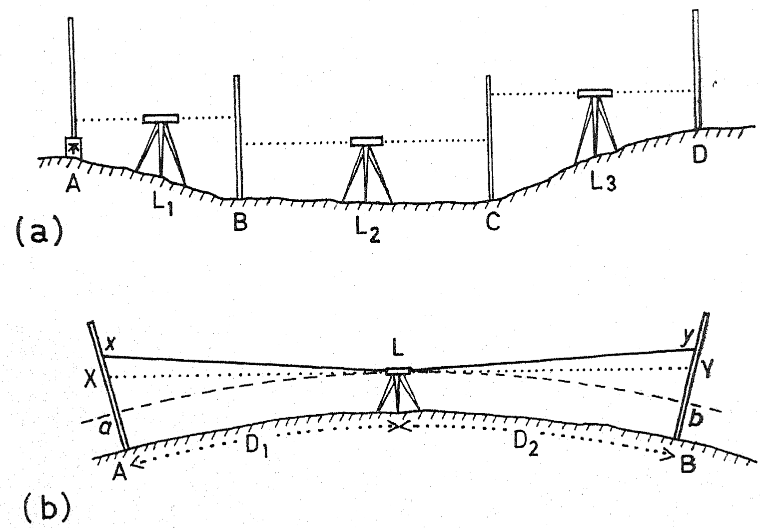

Fig. 4.

line through *L*, represented by *XLY* drawn perpendicular to the true vertical through *L*, diverges from the level line, giving differences of reading on the staff of *aX* and *bY* (this, when modified by refraction, equals approximately $4/7D^2$ ft, when *D* is given in miles). If the level is slightly out of adjustment the line of collimation may not be exactly horizontal when the bubble of the level is in its central position and so the actual line of sight will diverge (or converge) once more from the true level line. Fig. 4*b* shows that if $D_1 = D_2$, *aX* will equal *bY* and *Xx* will equal *Yy* and so, in

spite of the errors, the difference between the fore and the back readings will still represent the true difference of height between *A* and *B*.

It is almost impossible to read the staff at distances greater than about 200 yd and generally levelling sights seldom exceed 100 yd. Since at one furlong the error caused by curvature (modified by refraction) is only $\frac{1}{10}$ of an inch it is safe to ignore such errors entirely; nevertheless, since the error in collimation (*Xx* and *Yy*) is sometimes significant the length of the fore sight should, whenever possible, be made to agree with that of the corresponding back sight.

So that errors may be detected it is desirable that lines of level should

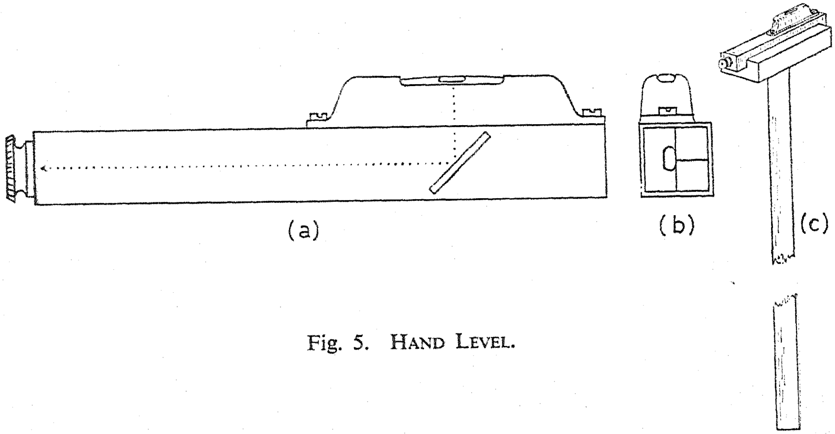

Fig. 5. HAND LEVEL.

start at one known height and finish on another (or the same) known height. Even if no absolute heights are known the accuracy of the field work may still be checked by finishing the line of levels on the starting point; but if absolute (as opposed to relative) heights are required it is necessary to include a point of known height somewhere in the line of levelling.

THE HAND LEVEL.—Spirit levelling may also be carried out with the hand level (or reflecting level). This is a pocket instrument consisting of a tube (frequently of square section) with a horizontal cross-hair at the front aperture. Mounted on top of the tube is a small spirit level, the bubble of which can be seen from the eye end of the instrument reflected from a

mirror in the left-hand half of the tube. To use the instrument, hold it horizontally so that the reflection of the bubble is seen against the cross-hair; any distant object cut by the cross-hair at the same time will be in the same horizontal plane as the instrument (Fig. 5*b*). The instrument is much easier to use and its accuracy greatly increased if it is mounted on an improvised stand, $4\frac{1}{2}$ or 5 ft high, as shown in Fig. 5*c*. They may be used with an ordinary levelling staff, but for the sake of portability it is usual to substitute a ranging pole graduated in feet and $\frac{1}{5}$ of a foot (0·2). Most hand levels are non-telescopic so that it is impossible to read the staff at a distance greater than about 100 ft.

THE THEODOLITE.—This instrument is described in Chapter IV. It can be used for determining heights by the operation known as trigonometrical

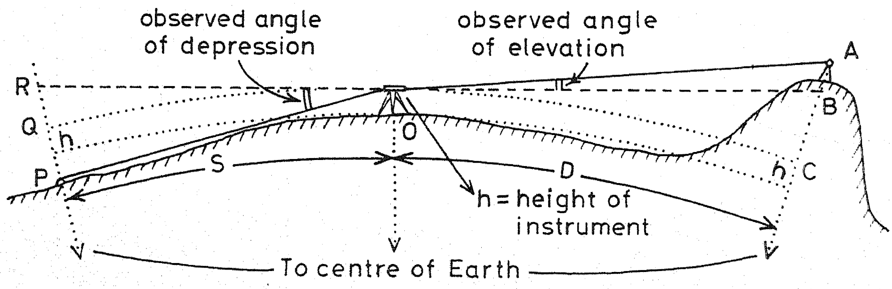

Fig. 6. TRIGONOMETRICAL LEVELLING.

RB is the horizontal plane drawn through the instrument.

$PR = S \tan$ depression.
$QR = \frac{4}{7}S^2$.
Difference of height between O and P
$= -PR + QR + h$.
(This will be a negative term when P is at a lower level than O.)

$AB = D \tan$ elevation.
$BC = \frac{4}{7}D^2$.
Difference of height between O and A
$= AB + BC + h$.

With a D (or S) of 10 miles an error of $\frac{1}{2}$ a minute in observing the elevation or depression will give an error in height of about $7\frac{3}{4}$ ft.

levelling. With this the vertical angle to the object, whose height is required, is observed and by multiplying the tangent of this observed angle by the horizontal (map) distance of the object from the observer the difference of height between the two may be obtained. The correction of $4/7D^2$ mentioned on p. 18 must be applied (see Fig. 6.)

THE CLINOMETER.—Clinometers are fairly crude instruments designed for measuring the vertical angles contained between a line of sight and the horizontal. Such measurements are required either for measuring the angle of slope of the ground or for measuring the vertical angles needed for trigonometrical levelling. To assist in the latter requirement they usually have two scales of graduation: one graduated in degrees and fractions (usually $\frac{1}{6}$) and the other in the natural tangents of the angles.

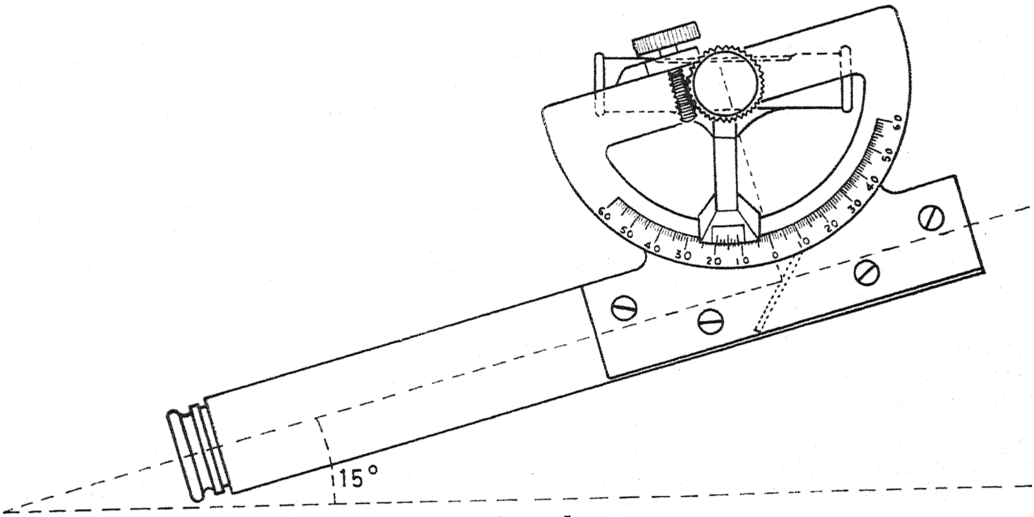

Fig. 7. ABNEY LEVEL.

The Abney Level (strictly Abney clinometer). This is a well known and popular clinometer. It is very similar to the hand level, but the spirit level instead of being mounted rigidly on the sighting tube is pivoted and turns round a graduated arc which is attached to the sighting tube. To use the instrument, the sighting tube is directed along a slope or towards some object whose height is required. The spirit level is then moved by a milled head until the bubble is seen reflected against the line of sight; this will have moved the index (frequently fitted with a vernier) across the arc so that the angle of elevation or depression may be read off. If the index is clamped at zero the instrument may be used as a hand level.

The Indian Clinometer. This is the most useful type of clinometer to use with the plane-table (see Chapter V). It consists of a base plate, about 9 in. long, on which is mounted a spirit level; using this level and an adjusting screw at the end of the plate the base can be made truly horizontal. Two folding sight vanes are erected at each end of the base plate; one,

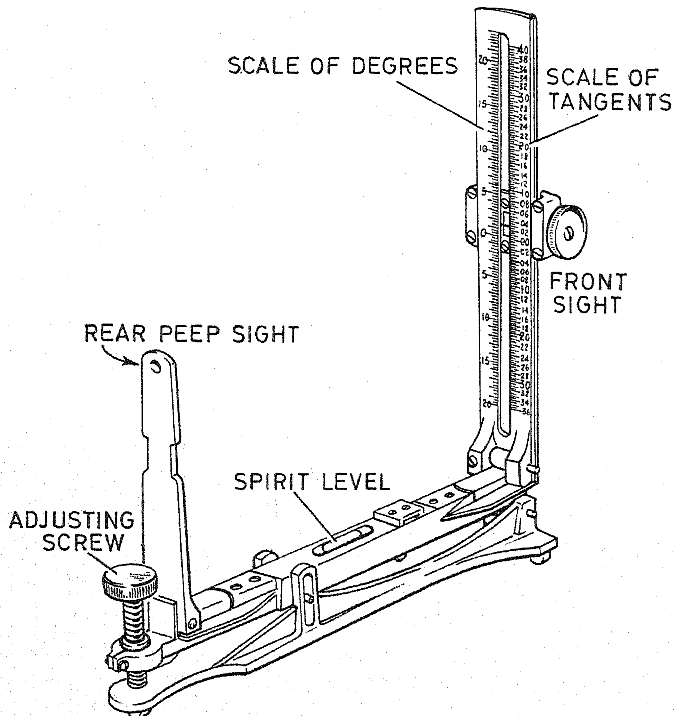

Fig. 8*a*. INDIAN CLINOMETER.

half the length of the other, has a small hole, peep sight, near its top, the other is graduated with degrees and tangents. When the base plate is properly levelled the line joining the peep sight to the zero of the graduations should be truly horizontal. To use the instrument, level the base plate and direct it towards the object whose height is required. With the eye a few inches from the peep sight, look through the hole and note the scale reading

opposite the object being observed; this is read off as the tangent, or ratio, by which the horizontal distance of the object from the observer must be multiplied to give the difference in height.

In Fig. 8*b* the tangent is $-$ 0·1, so if the object viewed is 500 ft away its top is 50 ft below the instrument.

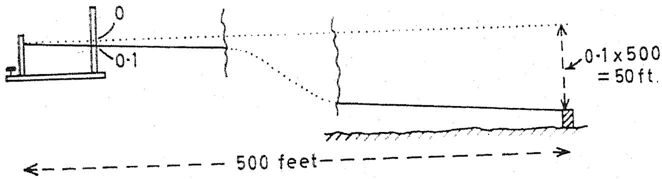

Fig. 8*b*.

NOTE (1) The height of the instrument above the ground must be taken into account and if the object is more than a mile away the curvature and refraction correction of $\frac{4}{7}D^2$ must be applied (see p. 18).

(2) The instrument has no telescope and so its effective range is limited to about three miles.

(3) Many instruments have a sighting wire which may be moved up and down the front sight by a milled head to coincide with the object observed.

THE ANEROID BAROMETER.—Surveying aneroid barometers vary greatly in detail, ranging from precision instruments which can, when the proper observing routine is carried out, determine heights to a couple of feet, to the cruder watch-type instruments which can be read only to 20 ft. All however have the same general design and principle of operation. All record changes of atmospheric pressure by means of the distortion of a delicate, hermetically sealed drum from which all air has been exhausted; this distortion is transferred by levers to a pointer moving across a clock face. The face is graduated in many different ways; in pressure units, millibars or inches of mercury, or in height units, usually feet; in many two scales are given and frequently the scale of feet may be rotated and set to agree with some known height at the start of a day's work.

Obtaining heights with such instruments is known as barometric levelling and its operation depends on the loss of atmospheric pressure with height. (A very rough and far from accurate rule is that the barometer

falls one inch of mercury per 1,000 ft elevation.) Since the normal daily change in atmospheric pressure also causes the height of the barometer to change it can readily be understood that barometric levelling must be severely "controlled". Perhaps the most convenient way for a single-handed topographer to do this is, during a day's barometric levelling, to visit known heights at intervals not exceeding about three hours, and to make proportional adjustment to the height observations made between

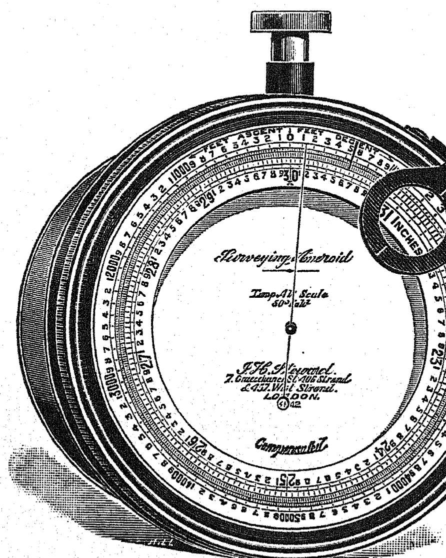

Fig. 9. HYPSOMETRIC ANEROID.

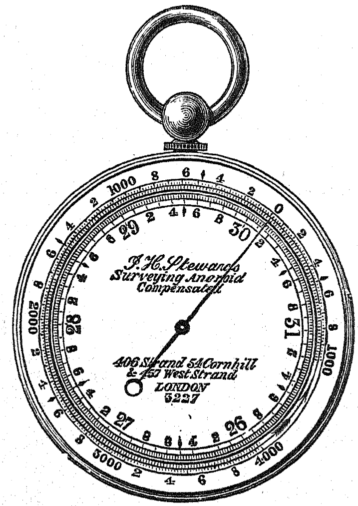

Fig. 10. OPEN RANGE ANEROID.

these checks, *e.g.* at 0900 the reading at a known point was 4 ft too high; at noon the reading at another known point was 8 ft too low, *i.e.* a change of error of 12 ft in three hours. Proportional corrections to be made to heights observed in the intervening period would be

0900 − 4 ft	1000 Nil	1100 + 4 ft	Noon + 8 ft
0930 − 2 ft	1030 + 2 ft	1130 + 6 ft	

Barometric levelling should not be carried out in unsettled weather when the atmospheric pressure is unstable.

Barometric levelling is particularly useful for finding the heights of points largely hidden from view, in deep valleys or in thickly wooded country, especially when there is adequate height "control" in the surrounding clear land.

4. CONTOURING

There are several different ways of contouring an area and the method chosen must depend on many factors: size of area; method by which it was surveyed and hence the scale and the density of the "control", both planimetric and height; means at the disposal of the surveyor in instruments and technical assistance; time available; vertical interval required; etc.

GRID LEVELLING.—For comparatively small open areas, say two or three fields in extent, the most convenient and accurate method is by grid levelling. This comprises three separate operations: (i) marking out, (ii) levelling, and (iii) interpolating the contours on the plan.

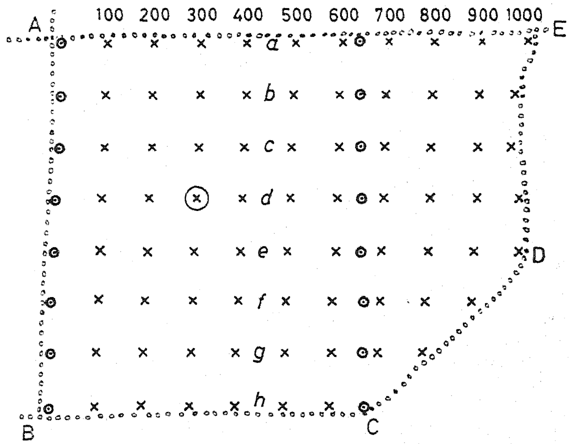

Fig. 11.

Fig. 11 shows the method of marking out the area, in this case the field *ABCDEA* which has been surveyed by a traverse (see Chapter VI).

Ranging poles (or gardening bamboos) can be set up at regular intervals along the hedge *AB* and at similar intervals along a line from *C* to the opposite hedge set out roughly parallel to *BA*. (If *BCD* was a straight hedge the poles would have been set up along the hedge *DE*.) Along each of the lines joining corresponding poles put twigs in the ground at regular intervals; these will mark the points where the grid levels or spot heights are required. The distance apart of the lines, and of the twigs along the lines, is dictated by the smoothness or otherwise of the ground. Common

distances are 50 ft or 100 ft, the former should not be exceeded in large scale work when extreme accuracy is required.

The levelling is then carried out by the ordinary levelling process as described on p. 17; first levelling from the nearest known height (possibly an Ordnance Survey benchmark) into the area and then up one line and down the next, etc.; checking back on the known height at frequent intervals. Care must be taken to avoid confusion in booking the levels; the best way of recording the individual spot heights is to allot letters to the lines and figures to the distance along the line, *e.g.* in Fig. 11 the spot height encircled would be booked as *d* 300.

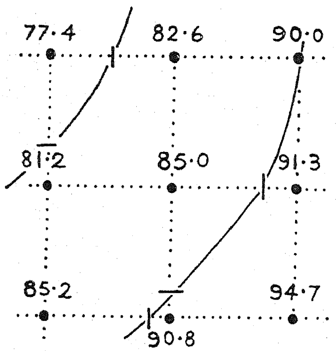

Fig. 12.

Finally the contours are interpolated on the drawn plan. The individual heights are pencilled in lightly and ticks made on the appropriate sides of the grid squares corresponding to the required contour—the ticks are then joined by a continuous line. Fig. 12 shows the 80 ft and the 90 ft contour interpolated on part of a grid.

Pegging in Contours.—This method needs two separate operations: (i) pegging in the required contours on the ground, and (ii) surveying the

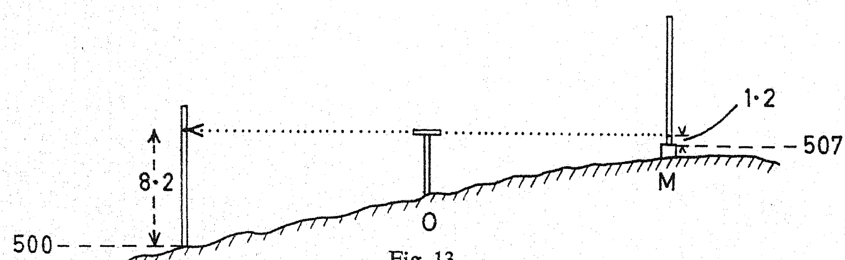

Fig. 13.

lines so pegged by traverse (see Chapter VI). Take, for example, a fairly steep hillside with a known height of say 507 ft near the top. Contours at 50 ft V.I. are required.

Using an ordinary spirit level, or, more conveniently a hand level, level down from the 507 ft mark to any point on the 500 ft contour as shown in Fig. 13. The staff (or pole) holder ties a piece of coloured rag round the pole and then stands the pole on the 507 ft mark, *M*. The observer moves down the hill to *O* until the horizontal line of sight from his hand level cuts the pole somewhere near the bottom. Suppose this is at 1·2 ft; it means that the height of the instrument at *O* is at $507 + 1{\cdot}2 = 508{\cdot}2$ ft. The rag is now slid to 8·2 ft on the pole, and the pole is taken down the hill until the horizontal line of sight cuts the rag. The bottom of the pole is then 8·2 ft below the level of the instrument at 508·2 ft, *i.e.* it is standing on the 500 ft contour. Leaving the pole where it is, the hand level, on its stand, is taken as nearly as can be guessed about 100 ft along the contour, is set up, and sighted back with the bubble central on to the pole. The pole holder moves the rag on the pole until it is cut by this new line of sight. When this has been done he leaves a twig to mark the spot and walks about twenty paces towards the level and stands his pole on the ground. The observer sights on to the pole and according to whether his horizontal line of sight cuts the pole above or below the rag he motions the pole holder up or down the hill; the pole holder moves and tries his pole in different positions until the horizontal line of sight cuts the rag again. The pole is once more on the 500 ft contour and the spot is marked by a twig. The pole is moved on another twenty paces and the procedure is repeated. (If on first sighting the observer tells the pole holder "You are 1½ ft too low" or "1 ft too high", the pole holder can usually find the right spot very quickly.) When the pole has reached a point 100 ft or so beyond the level, and the contour has been found, it is kept where it is, standing on the 500 ft contour, and the level is taken forward about 100 ft along the contour. The pole is sighted and the rag is adjusted to the new horizontal line of sight, and the whole process is repeated until the 500 ft contour has been pegged in, by the twigs, as far as it is required. It is then surveyed by traverse (see Chapter VI) and plotted on the map.

CONTOURING DOWN SLOPES.—On fairly steep slopes contouring can be carried out very quickly with a 10 ft pole, hand level, and tape.

Suppose the position of the summit, *X* Fig. 14, and its height have been found by triangulation, and the hill is to be contoured with a V.I. of 10 ft.

First peg in the next even 10 ft contour below the summit (in this case at 740 ft) by the method just given, and from this contour draw rays down any clearly defined spurs and re-entrants such as from *a*, *b*, and *c*, either as

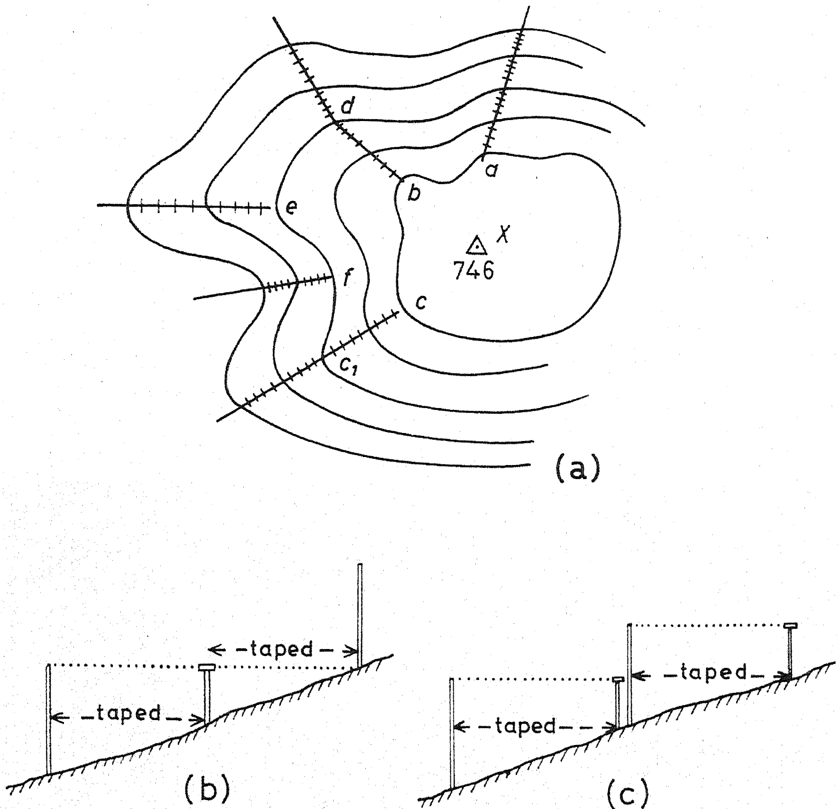

Fig. 14.

plane-table rays (Chapter V) or compass bearings (Chapter VI). Mark the direction of these rays on the ground by poles or bamboos. Level down the lines thus marked in 5 ft steps as illustrated in Fig. 14 (*b*) or (*c*); in (*b*) the 10 ft pole is held on the contour and the level, on a 5 ft stand, is taken

down the slope until the horizontal line of sight cuts the bottom of the 10 ft pole. The level then remains where it is and the pole is moved down the line until the horizontal line of sight cuts the top of the pole, which will then be standing on the 730 ft contour. The distances between staff and pole are measured by tape if they are less than 100 ft, but by pacing if they are more. Some people prefer to sight in one direction only, as shown in Fig. 14(*c*). (In this, the level stands on one 10 ft contour; the pole is taken down the hill until the line of sight cuts its top. When the distance between level and pole has been measured the level is moved to the position occupied by the pole and the process is repeated.) The distances between the contours are booked and can later be marked on the plan. At *d* the direction of the spur from *b* changes and this must be recorded on the plane-table or by a new compass bearing; at *e* and *f* new rays are required; the positions of *e* and *f* must first be found by pegging along the appropriate contour from c_1 or *d*; when the positions have been marked and the new rays plotted, the cutting points of the contours may be found as before. At each point where a required contour cuts a ray its general trend to right and left is noted; this will enable the contours to be drawn on the map with much greater veracity than would be obtained merely by joining one cutting point directly to the next.

CONTOURING BY USING HORIZONTAL EQUIVALENT.—As an alternative to the method just given, the slope of the ground down a ray may be measured by a clinometer and the contours spaced on the map by means of a scale of slopes (see p. 15) and the appropriate H.E. Except when the slope is very even this operation is generally slower and less accurate than the method previously described.

When measuring slopes it is generally more convenient to measure from the top of a 5 ft stand to the top of a pole of the same height, than along the ground itself where vision will be much impeded by tufts of grass and other obstructions.

CHAPTER IV

SURVEYING—I

1. TRIANGULATION

The large scale maps of a country ranging from scales of 1 : 2,500 (roughly 25 in. to the mile) to 1 : 250,000 (roughly 4 ml. to the inch) are known as topographical maps. (Maps drawn on a larger scale are usually termed cadastral maps and those on a smaller scale, atlas maps, see p. 3.)

Topography (Greek, *topos*, a place, *graphos*, written) has as one of its meanings the delineation of the various features of a district, and this exactly describes **topographical surveying** and the work of the topographical surveyor. The degree of accuracy with which a topographical survey is made depends largely on the scale of the survey for, in general, it is a waste of time and money to survey the topographical detail to a higher degree of accuracy than can be shown on the map; the thickness of a fine pencil line may be taken to be $\frac{1}{200}$ of an inch; on a scale of 1 in. to the mile this represents a width of 26 ft so, in theory, any features of less extent cannot be shown on the map. (The cartographer overcomes this difficulty by formalising and exaggerating important features, particularly the widths of main roads.) With well established national surveys, the principle of making the scale of the survey correspond with the scale of the map which is to be made from it, is not followed, *e.g.* the standard scale now adopted by the Ordnance Survey for rural areas is 1 : 2,500 and the smaller scale maps are made by a reduction from this large scale.

Travellers and explorers in the past have frequently made approximate observations of the relative positions of prominent objects along the routes they have travelled and in undeveloped countries these "route traverses" were often the only sources available for compiling the map. Later as the countries were opened up for development regularly constructed surveys were made and such early work could be discarded. Even before a regular survey could be made air photographs have enabled some route traverses to be amended and maps of greater accuracy to be made from them. It

may be said that the first thing necessary for the development of a country is a good map.

The work of the topographical surveyor is to portray and summarise the different features of the earth on a map; such features will be natural—hills, valleys, rivers, lakes, forests, etc., or artificial—buildings, roads, railways, field boundaries, etc.

A good topographical map should show the general relief of the country and as many of the surface features as can be included within the limits of the map scale. In very flat country, such as the Fenland, where such relief as there is may be less than the selected contour vertical interval, it is difficult to show the low undulations and eminences, which, comprising more solid masses of gravel or other glacial deposits, formed the sites of settlements when the surrounding fen was undrained marsh. As a contrast a highland region may have a complexity of surface features which may obscure the contoured relief. Ultimately it is the work of the cartographer rather than the surveyor to resolve these difficulties—by varying the contour interval, skilful use of colour and hill shading, etc.

The accuracy and consequently the usefulness of topographical maps varies according to the conditions under which the survey was made and the methods employed by the surveyors while making it. Surveys will range from the route traverses of explorers to those carried out with the greatest precision by national surveys. The date of the survey is a most useful and essential clue to the reliability of the map, but on many maps a "reliability" inset is printed which indicates which part of the map should be treated with suspicion because of the unreliable data from which it has been compiled. Usually the maps published as a series by the national survey departments of highly developed countries need no such guarantees though, of course, there is no denying that some maps are vastly superior to others.

The absolute accuracy (as opposed to the relative accuracy) of a topographical map depends on the accuracy of the framework on which it is based. The fundamental principle of the surveyor is "always survey from the whole to the part" which is another way of saying that an accurate framework must be surveyed first and then the detail surveyed, interpolated within the frame and not exterpolated outside it. Such a framework consists of a series of points whose positions have been fixed relatively to each other.

For the main or primary framework such points may be anything up to 100 miles apart, consequently a secondary framework and frequently a tertiary framework must be fixed within this primary framework. If the adjacent points of a random series of points are joined together by straight lines a series of triangles results and in the case of the map framework this is known as the **triangulation.** The relative positions of the various points of the framework may be determined in several ways, (1) triangulation, (2) precise traverse, (3) trilateration, (4) aerial triangulation, (5) astronomical observations; [(5) is the least accurate method and really should not be included in this list for by it the position of each point is fixed absolutely by astronomical observation and has no relationship with the position of adjacent points. It is used only on small scale exploratory surveys.] Until comparatively recently it could be said that triangulation was the most accurate method of control that could be adopted (so it usually was); but in recent years, especially in thickly forested countries where long rays cannot be observed by theodolite, very accurate control (framework) has been established by precise traversing [akin to ordinary traversing (see p. 59) but with the angular and linear measurements made with great precision using the most up-to-date instruments]. Trilateration is a new method of triangulation in which the sides of the triangles are measured instead of the angles (see later) and has been made possible only by the recent invention of instruments such as the *geodimeter* and *tellurometer* which enable long distances, thirty miles or more, to be measured almost instantaneously with great accuracy. (The geodimeter measures the time a light wave takes to travel from one point to another; the tellurometer does the same thing with radio waves.) A triangulation can be carried out from the air, but when this is done it is usually for minor triangulation between points that have already been fixed by one of the other methods just mentioned.

2. TRIANGULATION—PRINCIPLES

Until the invention of the geodimeter and tellurometer the measurement of long lines, of ten miles or so, on the surface of the earth was such a long and tedious business that the surveyor took advantage of the facts (1) that the three angles of a triangle sum up to 180°, and (2) that if the length of one side of a triangle is known and also the value of the three angles, the

lengths of the other two sides may be calculated by trigonometry. Thus in Fig. 15 in the triangle ABC if the length of AC is known and the angles at A between B and C and at B between A and C have been measured the length of BC can be calculated. When the angles at B, C, and D in the triangle BCD have been measured, sufficient data is available for calculating the lengths of BD and CD, and so on. In theory, two angles only in each triangle need be measured but the surveyor always prefers to check his observations (and assess their reliability) by measuring the third angle. Similarly, after calculating CD in the triangle BCD, the lengths of CF and DF in the triangle CDF may be determined and hence the position of F, but as a check the surveyor will also observe the angle to F from B and thus be able to find the position of F from the triangles BCF and BDF as well. The apices of the triangles, the points A, B, C, etc., are known as *triangulation stations* or trigonometrical points ("trig" points); they are usually symbolised on maps by a small triangle △ and are generally marked on the ground by some form of beacon—the white pillars, about 4½ ft high, which mark the Ordnance Survey triangulation stations will be familiar to all observant geographers. It can thus be seen that in the complete network of triangles covering the whole country only one side need be measured; this is known as the **base.** It will be appreciated, however, that two more important pieces of information are necessary before the "absolute" positions of the stations are known; (1) the orientation or direction of the base must be known, and (2) the latitude and longitude of one of the stations at the ends of the base must be known. This data is obtained by separate astronomical observations for position and azimuth (or bearing) of one end of the base from the other.

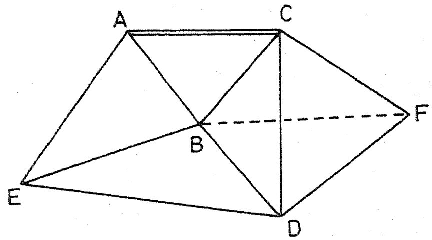

Fig. 15.

3. TYPES OF TRIANGULATION

There are several types or orders of triangulation.

Geodetic or Primary Triangulation.—This is the name given to the main framework of a national survey and also to the operation of forming it.

It is carried out by experienced observers using precise instruments and the most refined methods of observation. It tends to be a long and expensive operation. The sides of the individual triangles will probably be about thirty miles or more long and errors of misclosure of triangles (*i.e.* the difference between the sum of the three angles and 180°)[1] greater than 1″ of arc are not tolerated.

SECONDARY TRIANGULATION.—Obviously, for fixing points of topographical detail, many more known points will be required than the comparatively few supplied by the primary triangulation; so, within the main triangles of this primary network another network of smaller triangles is made with sides of about ten miles or less. This is the secondary triangulation and since it is "tied" rigidly to the primary triangulation less precision is needed in the observation and triangular misclosures of 5″ or so can be tolerated.

TERTIARY TRIANGULATION.—Just as the primary triangulation was broken down into smaller units by the secondary, so the secondary triangulation is broken down into triangles with side lengths of one mile or so by the tertiary triangulation. Angular misclosures of up to 15″ may be tolerated.

(Note, in small countries where only one breakdown of the primary triangulation is necessary, the terms major and minor triangulations are sometimes used instead of the above.)

TOPOGRAPHICAL TRIANGULATION.—It is frequently necessary for the topographical survey to start before all the triangulation detailed above has been completed so a special topographical triangulation may be made to provide sufficient "fixed" points to enable the detail surveyors to carry out their plane-tabling and traversing (see Chapters V and VI). Such a triangulation will have sides of 1 to 5 ml. long and will permit misclosures up to 30″ of arc, *i.e.* roughly akin to tertiary triangulation.

The above details are of interest chiefly for showing the elaborate procedure necessary for constructing reliable maps; there is no need, at

[1] This statement is not strictly true. The angles of a spherical triangle, such as are measured during a triangulation, sum up to *more* than 180° by an amount known as the "spherical excess", which is roughly 1″ per 76 sq. ml. of the triangular area. This may readily be appreciated by looking, on a globe, at the spherical triangle formed by the north pole and two points on the equator 90° of longitude apart. In such a triangle each of the three angles is 90°, *i.e.* the sum of the angles is 270°, and the spherical excess is 90°.

this stage, to trouble about the technique involved. Those who are interested to know more should consult the bibliography on pp. 259 and 260.

4. THE THEODOLITE

When making a surveying plan, or measuring the planimetry of a map, it is essential that *all* measurements must be truly horizontal, linear (see p. 65e, Fig. 37a) and angular. The theodolite is an instrument designed to measure the *horizontal* angle between two points, however much they differ in altitude. It consists of (1) a telescope, *T*, fitted with trunnions, *t*, and free to be elevated or depressed (and, in modern instruments, free to be turned vertically through 360°). A graduated arc, *V*, is attached to the telescope, which moving past indexes, *mm*, allow the vertical angles of elevation or depression to be read. The trunnion bearings are carried by (2) the *upper plate*, *H*, to which are affixed the two indexes, *vv*. This upper plate has a vertical axis which fits inside the hollow vertical axis of (3) the *lower plate*. This lower plate is graduated through 360° and can be clamped in any setting required. The indexes, *vv*, moving over the graduated arc enable horizontal angular readings to be made when the telescope is directed on to any object. The twin vertical axes of the upper and lower plates are fitted into (4) the *tribrach*, which has three (occasionally four) levelling screws, *lll*, to enable the instrument to be truly "levelled". The tribrach is screwed on to (5) the *tripod*. To enable the theodolite to be levelled a sensitive spirit level, the "plate" level, *p*, is fitted on the upper plate. To supply the zero for vertical angles a still more sensitive spirit level, the "altitude" level, *s*, is attached to the arm carrying the indexes, *mm*. In addition every moving part is supplied with a clamp, *ccc*, and a slow motion screw, *nnn*. To enable the instrument to be accurately centred over a station mark a plumb bob may be hooked to the bottom of the vertical axis.

Theodolites differ greatly in detail design, in the closeness of their graduations and in the devices employed for reading them—the "indexes" referred to above. These may be verniers or micrometer microscopes, but in most modern instruments the graduations are scribed on glass arcs and optical arrangements within the instrument enable the "angles" to be read, usually through an additional telescope (not shown in Fig. 16).

The telescope, a powerful one, is similar to that of the spirit level described on p. 17. It is fitted with cross-hairs and has two separate focusing adjustments, one, controlled by a revolving eyepiece, focuses the cross-hairs, the other, controlled by a milled screw on the side of the telescope (or by a milled revolving section of the telescope barrel) allows the telescope to be focused on to the object being observed.

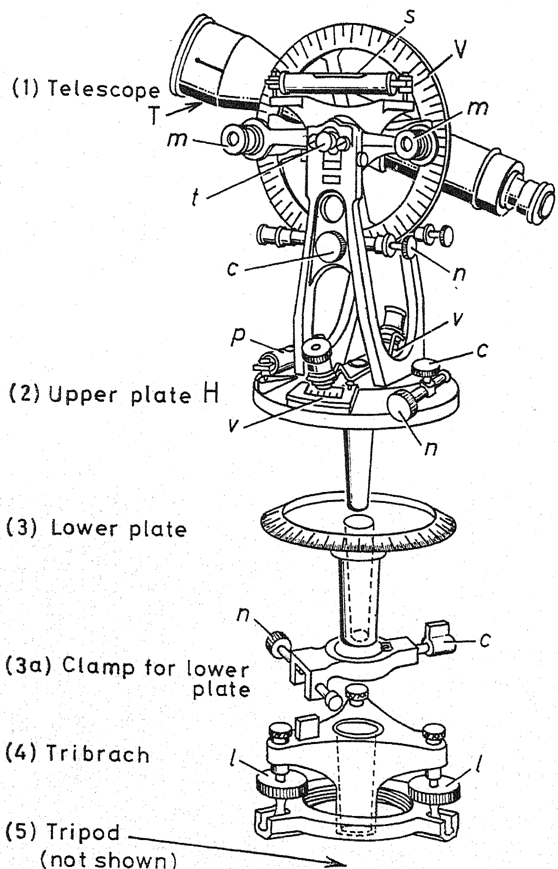

Fig. 16.

Theodolites vary greatly in precision (and cost) but all are delicate and expensive instruments and considerable experience and skill is necessary before full value can be obtained from them. Like all delicate surveying instruments they are prone to certain instrumental errors which can be eradicated when sufficient expertise has been gained, but apart from adjusting the instrument, most of the *effects* of maladjustment may be nullified by the operation known as "changing face". A theodolite is said to "face left" when the vertical arc, V in Fig. 16, is on the left of the telescope; when the telescope is transitted, *i.e.* turned over so that it points in the opposite direction, the vertical arc is on the right of the telescope and it is said to "face right". When observing a "round of angles" the

observations are first made on one face; face is then changed and the whole series is repeated on the other face. The mean of the values observed—either horizontal or vertical angles—will be free of all, save one, instrumental maladjustments. The one not cured by changing face is faulty levelling of the instrument; it is therefore exceedingly important that the levelling screws, *lll*, shall be so adjusted that the bubble of the plate level, *p*, in Fig. 16, shall remain in the same position whatever direction the telescope may be pointing. This "same" position is usually the central one, but if the plate level itself is slightly out of adjustment the "same" position may be one or two divisions (as graduated on the bubble tube) out of centre.

Surveyors use different observational routines when observing with the theodolite, but the one described below suffices for most topographical needs.

OBSERVING WITH THE THEODOLITE.—Referring to Fig. 15. Suppose observations are to be made at *B*.

Set up the theodolite with the tripod legs pressed firmly into the ground and the vertical axis vertically over the station mark (usually a certain amount of adjustment is needed before this can be achieved satisfactorily). Now, by means of the foot screws level the theodolite and then focus the telescope, cross-hairs first. Next, clamp the upper plate to the lower in such a position that the reading of the "*A*" index is roughly 000°. With the two plates thus clamped but free to revolve together direct the telescope on to the clearest of the objects to be observed; this will then, throughout the series of observations, be the referring object, the R.O. Clamp the lower plate and leave it clamped throughout the whole of the first two rounds of angles. Unclamp the upper plate and direct the telescope on to the R.O., say *A* △. This is done by revolving the telescope by hand until it is seen in the field of view of the telescope, the upper plate is then clamped and the last piece of directing is done with the slow motion tangent screw until the centre of the cross-hairs is exactly on *A* △ mark; read and book the horizontal arc; then, in turn direct on to stations *C*, *D*, and *E*, reading and booking the horizontal arc each time. Finally, direct on to *A* △ again and read and book the horizontal arc; this is called "closing the horizon" (the reading should agree within 40″ of the initial reading). Now with the lower plate still clamped, release the upper plate, change face, and again direct on to the R.O. Read and book the horizontal arc. If the instrument

is in perfect adjustment this reading will differ from the original one by exactly 180°; then observe all the stations a second time—the second "round"—in precisely the same manner as the first round save that the order of observing should be *A, E, D, C, A*. (Actually, although important in geodetic work, the direction of the swing has little significance in topographical triangulation.)

The vertical angles may be observed at the same time as the horizontal or they may be observed in separate rounds. The observations differ from those of the horizontal angles in two ways. (1) It is essential that the bubble of the altitude level, *s* in Fig. 16, is in the centre of its run when the observation is made; a special tangent screw [roughly corresponding to the tilting screw of the spirit level (see Fig. 3)] is fitted in all modern theodolites to enable this to be done. (2) The vertical arcs of theodolites are graduated in many different ways but in no case will the face left reading differ from the face right by 180° (obviously the line of sight 180° opposite an elevation becomes a depression, whereas the reading to an elevated station must remain an elevation whichever face the instrument is on).

A convenient form of booking, with explanatory notes, is given opposite.

5. TRIANGULATION OF AN ISLAND

This chapter may be summarised by considering the opening stages of the survey of an island, illustrated in Fig. 17. These opening stages are:—

(i) *Reconnaissance and beaconing*. A rough reconnaissance survey is made, possibly by plane-table (see Chapter V). Sites for triangulation stations are selected and beacons erected on these sites. The sites will be chosen where there is good all round visibility and where the triangles formed by adjacent stations are "well conditioned", *i.e.* no angles are very acute or very obtuse (angles smaller than 40° or greater than 140° are usually avoided). In addition the perimeter stations are selected so that as little detail as possible will fall outside the triangulated framework. During the reconnaissance smooth clear ground suitable for base measurement will be noted.

(ii) *Angular measurement*. Carried out by observers using the method just described, save that at least eight rounds would be observed at each station and the mean accepted.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
			Horizontal Reading					Vertical Reading		
Observing Station	Station Obsvd	Face and Swing	A	B	Mean		Difference	C	D	Mean
			° ′ ″	′ ″	° ′ ″	° ′ ″		° ′ ″	′ ″	
B△	A△	F.L. Sw.R.	000 02 30	02 10	000 02 20	000 02 40		+1 20 00	20 00	+1° 22′ 07″
Ht of		F.R. Sw.L.	180 03 00	03 00	03 00		∠*ABC*	+1 24 00	24 30	
Inst.	C△	F.L. Sw.R.	059 31 20	31 40	059 31 30	059 31 50	59° 29′ 10″	−4 10 00	10 30	−4° 07′ 42″
4·3 ft		F.R. Sw.L.	239 32 00	32 20	32 10		∠*CBD*	−4 05 20	05 00	
	D△	F.L. Sw.R.	177 46 00	46 00	177 46 00	177 46 25	118° 14′ 35″	+2 36 00	36 00	+2° 38′ 22″
		F.R. Sw.L.	357 47 00	46 40	46 50		∠*DBE*	+2 41 00	40 30	
	E△	F.L. Sw.R.	279 11 30	11 30	279 11 30	279 12 00	101° 25′ 35″	+0 51 30	52 00	+0° 54′ 00″
		F.R. Sw.L.	099 12 20	12 40	12 30		∠*ABE*	+0 56 00	56 30	
	A△	F.L. Sw.R.	000 03 00	02 40	000 02 50	000 03 15	80° 51′ 15″			
		F.R. Sw.L.	180 03 30	03 50	03 40					
						(Sum)	360° 00′ 35″			

1. The height of the instrument in Col. (1) is important when vertical heights are to be calculated.
2. It will be noted that the first station, the R.O., is repeated at the end of the round. This is a check; the final reading should not differ more than 40″ from the original. (In precise work it will not differ by more than 1″.)
3. Cols. (5) and (10) are the readings of the *B* and *D* verniers or microscopes, placed diametrically opposite the ones labelled *A* and *C*. In many theodolites these do not exist, or if they do, possibly the rough nature of the work makes it unnecessary to read them. In such cases Cols. (5), (6), and (10) may be omitted from the booking.
4. It will be noticed that in Cols. (5) and (10) the readings of the degrees of Cols. (4) and (9) are ignored.
5. The sum of the angles at the foot of Col. (8) should add up to 360° whenever the "horizon has been closed". In this case it is 35″ in excess, so 8″ would be subtracted from the first angle and 9″ from each of the other three.
6. In Cols. (9) and (10) it will be noticed that the F.R. and F.L. readings differ considerably. This is not uncommon, but it will also be noticed that the F.R. readings are consistently about 4′ 30″ greater than the F.L. The consistency of this difference is a test of good observation.

(iii) *Base measurement*. On a site selected during the reconnaissance a base would be measured, using invar tapes, probably supported clear of the ground, on tripods, so that the tape hangs in a catenary curve. Such a base might be anything up to ten miles long. If the necessary equipment was not available the base would have to be measured "on the flat", *i.e.* along ground which has been carefully smoothed before the measurement. The preparation for this type of base is so long and laborious, that usually they are kept short and seldom exceed about two miles. In both cases every conceivable precaution is taken to eliminate errors; of these the three most important are: (*a*) comparing the measuring tape with one which has

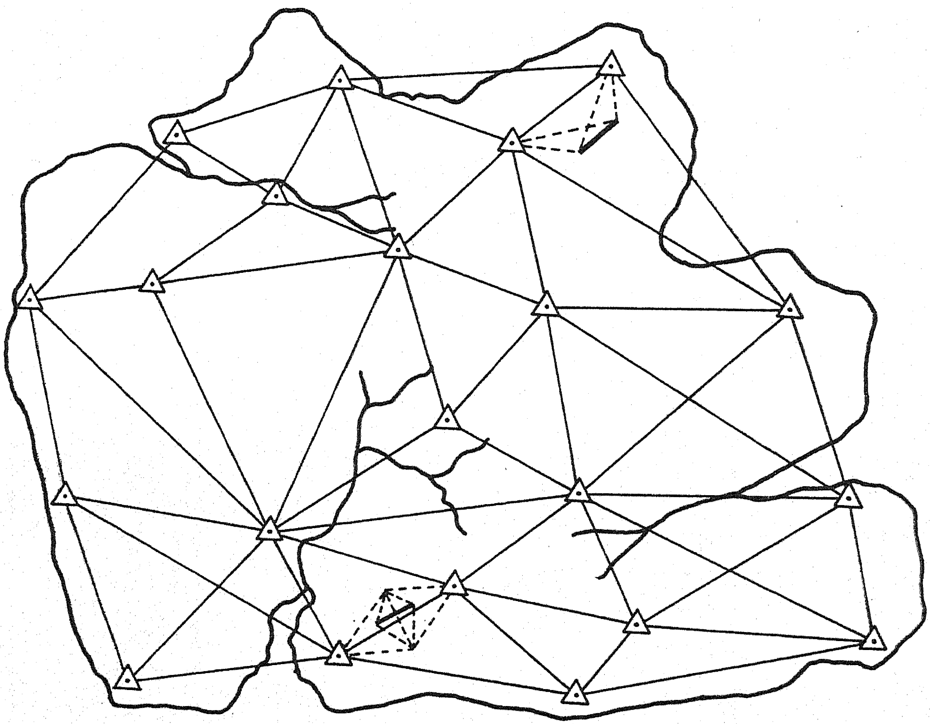

Fig. 17.

recently been standardised at the National Physical Laboratory, (*b*) making allowance for the expansion, or contraction of the tape during the measurement caused by changes in the temperature, and (*c*) making allowance for the slope of the ground.

(iv) *Base extension triangulation*. It is sometimes possible to measure the base along one of the sides of the triangulation, but more frequently it is not possible so a separate base extension triangulation is necessary, as shown in pecked line in Fig. 17, to extend the base on to the nearest side of the main triangulation.

(v) *Checks*. Dubious angles, if any, are repeated and, if the triangulation extends more than 200 miles probably a check base will be measured.

(vi) *Astronomical observations*. Astronomical observations for latitude and longitude will be made at one of the stations; and observations for azimuth will be made at the same station and probably two or three others to determine the orientation of the survey.

(vii) *Computation and adjustment*. Rough and ready computations are made as the triangulation proceeds so that the positions of sufficient points can be determined to enable the detail surveyors to start work. But the complete computation and adjustment of the triangulation (to compensate for such small errors that have occurred) is long and tedious (though, of course, far less so since the advent of electronic computors).

The topographical surveyors will then fill in the topography within the triangulated framework by plane-table or traverse and this will complete the planimetry of the map. The relief will be supplied by contouring within the height control established by trigonometrical levelling during the triangulation and the additional control obtained by spirit levelling. A datum for the levelling must be established by a series of observations of high and low water to obtain the height of mean sea level.

CHAPTER V

SURVEYING—II

THE PLANE-TABLE

The plane-table is a most useful piece of surveying equipment. In regular surveys it is used for surveying the topographical detail within the control supplied by triangulation or other orthodox methods. But in sketch and exploratory surveys it is possible to carry out a complete survey on the plane-table, first plotting a graphical triangulation (or control traverse) and then, or at the same time, filling in the topographical detail within the graphical control. (It should be noted that, as far as national survey departments are concerned the plane-table has now been almost entirely superseded by photogrammetry, chiefly from the air, as the staple means of surveying the topographical detail.)

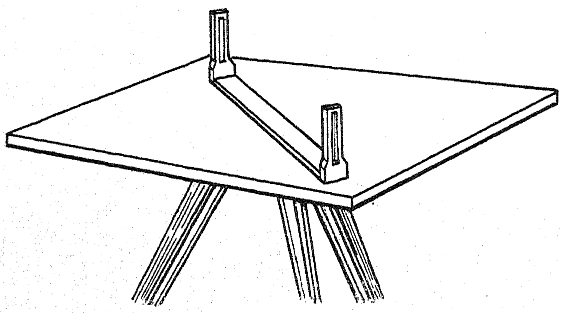

Fig. 18. PLANE-TABLE AND ALIDADE.

1. EQUIPMENT

The plane-table is simply a drawing board, covered with paper, mounted horizontally on a tripod. Elaborate refinements are fitted to some, chiefly in respect to the tripod head and the means of levelling the table. These refinements are undoubtedly useful but, on account of their extra weight and expense, many prefer to do without them.

The **table** (Fig. 18). This may be of any size but for normal field work 18 in. × 18 in. or 18 in. × 24 in. are the most useful sizes. The underside of the table must be fitted with some sort of socket to enable the table to be mounted on the tripod.

The **tripod**. The tripod legs may be rigid or telescopic; the former are the better because rigidity of the table, when set up for use, is essential;

however, convenience in transport makes the telescopic variety very popular. The tripod when standing with a good spread of the legs should be at least four feet high, and a few tall observers may prefer it higher still. The tripod head must have some form of pivot, so that the table may be rotated in a horizontal plane, and also some form of clamping screw to hold it steady when it is correctly orientated. Wing nuts to firm the tops of the tripod legs are almost essential.

The **alidade** or sight rule is the other essential part of the equipment. This may be of several patterns, the simplest of which consists of a stout boxwood ruler, 12 in., 15 in., or 18 in. long, on which are mounted the sight vanes, usually about 3 in. high. The rear vane has a narrow vertical slit; the front one has a wider slot, down the middle of which is stretched a vertical wire. It is essential that the sight vanes, when erected, shall be perpendicular to the base of the ruler. A thread stretched between the tops of the vanes is useful when sighting on to objects that are much above or below the observer. It is desirable, though not essential, that the line of sight should be parallel to the ruling edge. The *same* ruling edge, right or left of the sight vanes as is most convenient, *must* be used throughout. Useful additions are a parallel arm attached to one side (see Fig. 19), so that a ray, when observed, may be transferred exactly to or from the point of observation (see p. 55); and a spirit level (a small spirit level is desirable for setting the table horizontal and if it is permanently mounted on the alidade it will not be mislaid). Most alidades are graduated and it is a great convenience if the graduations correspond to the scale of the work being carried out. If such a one is not available perhaps the most useful all-purpose graduation is inches and fiftieths of an inch.

The **telescopic alidade** (Fig. 19). When long sights are involved a telescopic alidade is most desirable. In this type, a theodolite telescope, fitted with a vertical arc (and, usually with stadia hairs[1]), replaces the sight vanes; the vertical arc makes a clinometer (see below) unnecessary.

The **Indian clinometer** or abney level (see pp. 21-2) is an essential piece of equipment if relief is to be surveyed without recourse to levelling.

The **compass.** A compass is needed and although an ordinary prismatic compass can be used, it is better to have a trough (or box) compass. In

[1] These hairs may be used in conjunction with a graduated staff for the optical measurement of distances by tacheometry.

this a magnetic needle about 5 in. long is mounted on a pivot in a parallel-sided oblong box with a glass roof; by using the side of the box as a ruler the magnetic meridian may be drawn on the table when the needle is at rest (Fig. 20).

Other accessories, apart from those needed for drawing—pencils, rubber, penknife, etc., which are almost essential—are binoculars (for distinguishing

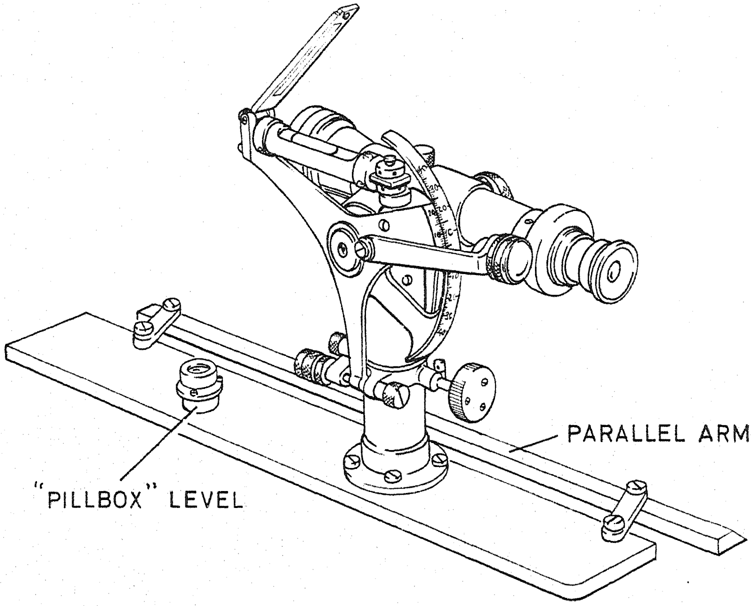

Fig. 19. TELESCOPIC ALIDADE.

distant points of detail); a boxwood scale if the alidade is not graduated; a small spirit level if one is not attached to the alidade; a note-book for recording rough notes, heights, etc. (to save over much writing on the table); a waterproof cover for the table; and a few short bamboos with small flags, for the temporary marking of points which are otherwise difficult to identify.

Good paper should be used on the table to minimise the inevitable distortions due to the humidity of the air, and this should be mounted on the table either by paste, clamps, or pins. If the work is likely to occupy

a long period the pasting method is easily the best—detailed descriptions of how to cut the paper and apply the paste are given in many surveying textbooks. For jobs that are not going to occupy more than a couple of

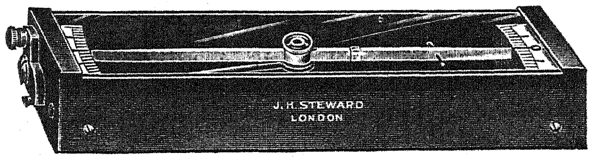

Fig. 20. Metal Trough Compass.

days, drawing pins may be used; they must be inserted in the overlap of the paper to the *under-side* of the table; it is absolutely essential that nothing projects above the top-side which might obstruct the alidade as it is moved about the table.

2. SETTING UP THE TABLE

When setting up the table see that the tripod is firm with a good spread on the legs and adjusted to a convenient height (about elbow height). Tighten the leg wing nuts. (When setting up on a slope, two legs should be down the slope and the other one up it.) The table must be *levelled*; by levelling screws or ball and socket attachment in the more elaborate tripods; by manipulating the legs in the plain variety. With telescopic legs, the final levelling adjustment may be carried out by shortening the highest leg rather than moving the feet. The small spirit level will be used for this operation but, if one is not carried, level the table by eye and then test, in two directions by seeing if a round pencil will roll on it. It must be *centred* over the exact station mark (for topographical purposes this condition is satisfied if any part of the table is over the mark). It must be correctly *orientated*, *i.e.* it must be so placed that the line joining any two points on the table and the line joining the corresponding points on the ground lie in parallel planes (see later).

3. METHODS OF SURVEYING WITH THE PLANE-TABLE

There are four methods: (i) Radiation, (ii) Intersection, (iii) Traversing, and (iv) Resection.

Radiation is of great importance in large scale work and many sites may be surveyed by radiation from a single commanding position. In small-scale work the topographical detail in the near vicinity of the table may be plotted by this method.

Set up the table in a commanding position in the middle of the site;

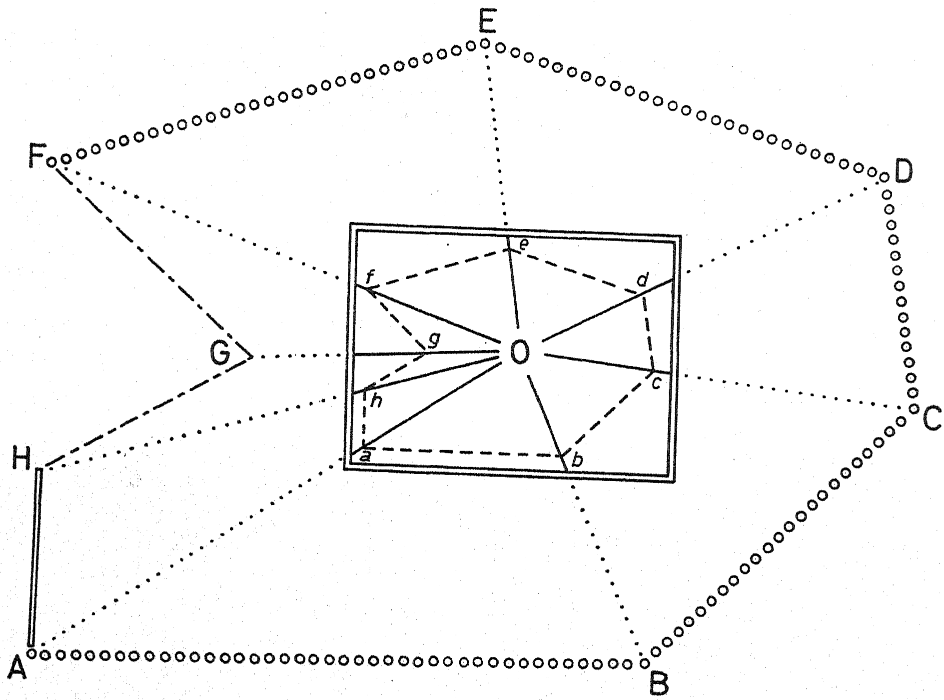

Fig. 21. RADIATION.

prick off a point in the middle of the table to represent this position, *O*, and draw radiating lines from *O* to all points it is wished to plot. Measure the distance from the table to these positions and plot them, according to scale, on the table (see Fig. 21).

Intersection. This is the method most used for plotting detail, and is also the method by which a whole survey may be made, controlled by a

graphical triangulation. It may best be illustrated by describing such a complete plane-table survey.

First select a *base* for the survey; a flat site centrally placed is desirable, where linear measurement can be made with accuracy. It is essential that the ends of the base shall be intervisible and that good all-round views are obtainable from each end. Bases should be from half a mile to a mile long, though for small areas a shorter one will suffice. It is important that the first base extension should be by well-conditioned triangles (see p. 38). Fig. 22 shows base extensions (i) for a base placed in the middle of the survey, and (ii) for one placed on one side.

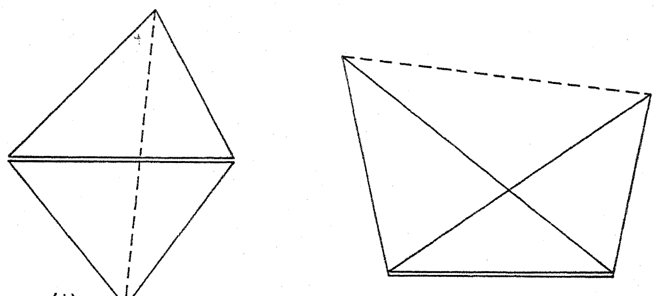

Fig. 22.

Mark the ends of the base and measure its length by tape, chain, or pacing. (An error in measuring the base results in an error in the scale of the survey. It need not impair the relative accuracy of the work and it is always possible to amend the scale by an accurate measurement later on—hence pacing suffices if time, at the start of the survey, is short.) Rule a line on the table to represent this base, placing it in the same relative position on the table as the base bears to the survey as a whole. Mark the ends with fine prick holes, the correct distance apart according to the scale of the survey.

Set up the table over station, *A*, at one end of the base and level it. Place the alidade on the table so that its ruling edge coincides with the drawn base-line and turn the table until the sights of the alidade point at the mark left at station, *B*, at the other end of the base (Fig. 23). Clamp

the table in this position and then draw rays to all the points which have been selected as later stations and to all points that are to be intersected, usually salient points such as the corners of buildings or conspicuous marks, lone trees, and the like (see p. 55 for tips on drawing rays). It is as well to identify each station by name and to write this along the ray. It is useful to draw the magnetic meridian on the table before leaving. Put the box compass on the table and turn it on top of the table slowly (the table still clamped) until the needle comes "alive"; continue turning slowly until the needle is exactly over the centres of the short scales in the box. Then rule in the meridian, using the side of the box as a ruler.

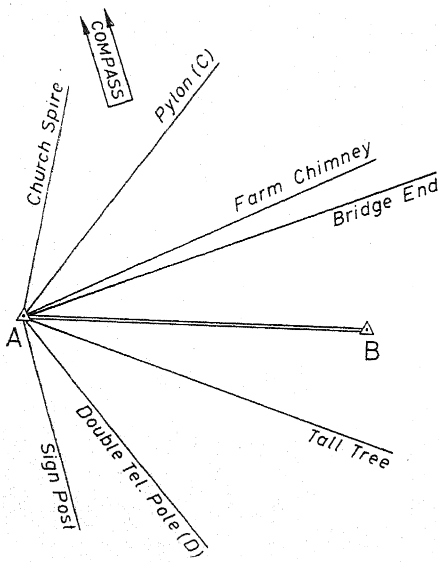

Fig. 23. GRAPHICAL TRIANGULATION I.

Next move the table to the other end of the base, *B*, leaving a mark at *A* for ready identification. (Note, it is customary to carry the table on its tripod and not to dismantle it each time.) Set up over station, *B*, level the table, and orient it as before by placing the ruling edge of the alidade along the drawn base and then turning the table until the line of sight coincides with the mark left at *A*. Clamp the table and draw rays from *B* towards all the stations and conspicuous points previously rayed from *A*. The point of intersection of corresponding rays is the map position of the intersected points; the names of the points should be inserted against the intersections. The table will now look like Fig. 24 save for one important detail and that is that no more of any ray should be ruled than is absolutely necessary (see p. 55). Next visit one of the base extension stations, say *C*, which has already two intersecting rays through it, and orient the table by sighting back to *A* or *B*, whichever is the farthest away. Check this orientation by sighting on to the other end of the base and, if it checks, draw rays to all other intersected points, particularly station *D*, the other end of the

base extension (Fig. 25). If the work has been well done the three intersecting lines at any one station will cut in a point. Should a **triangle of error** appear at a point, visit a fourth station, one where there is perfect intersection, and obtain a fourth ray into the doubtful position. The framework of stations, the triangulation, is now complete and the intersections should be pricked through and encircled in ink and superfluous pencil lines erased. (Note, however, that the rubber should be used sparingly,

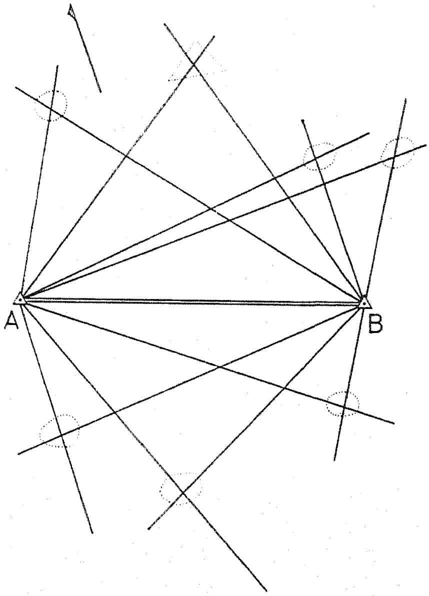

Fig. 24. GRAPHICAL TRIANGULATION II.

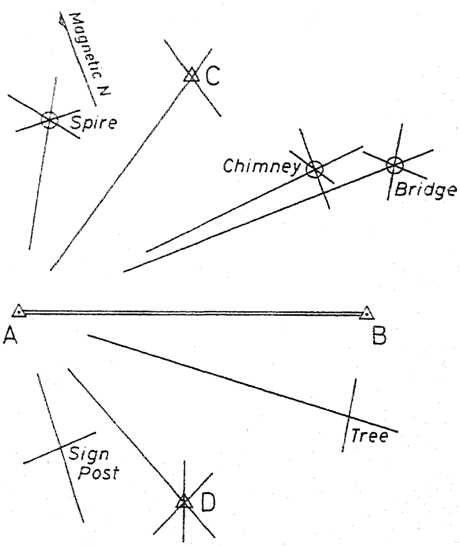

Fig. 25. GRAPHICAL TRIANGULATION III.

for every application spoils the surface of the paper a little, especially if the air is very humid.)

Should there be many faulty intersections and triangles of error (often referred to as "cocked hats") the rays from the ends of the base line must be suspected and it will usually pay to start all over again. (The probable cause of a series of faulty rays is inefficient clamping of the table so that it moves slightly from its initial orientation. It is a wise precaution to check that the orientation has not changed before setting off for the next set up.)

The stations may now be revisited for plotting the detail. This will be done by further intersection (for unimportant detail two intersecting rays are often sufficient provided they make a "good cut" nearly at right angles) and by radiation.

An experienced surveyor will plot the detail while he carries out the triangulation; in fact an old surveyor's dictum is "that only a fool needs to visit the same station twice"; nevertheless, it is better for beginners to make sure of the triangulation before starting on the detail.

Good points for intersection are bridges, the most conspicuous chimney of a house, etc., and especially field corners. When the field pattern is plotted further detail seems to fall into place automatically. Keep the eye open for long straight lines, say a long wall, a long section of straight road, a line of pylons, etc.; if such a straight line is seen radiating from the station occupied, always draw a ray to it, even if it is quite distant; it may be a most useful check some time later.

Heights and contours. If the survey is to be complete heights and contours will be required. If there is no known height in the area an arbitrary height for *A* must be assumed as a datum and all other heights referred to it. The heights of all intersected points may be determined by trigonometrical levelling, using the Indian clinometer (abney level or telescopic alidade) for observing elevations and depressions at every station before moving on to the next. It must be remembered that for contouring it is the ground heights that are required, not the *tops* of buildings, trees, etc. Except for station *B* no heights can be calculated from the observed elevations and depressions until the intersections have been completed, enabling distances to be scaled off. For station *B* a difference of height will have been observed from *A*; and from *B* a difference of height will have been observed to *A*, thus giving two values from which a mean can be accepted. Thenceforth all the chief intersected points will have at least three values from which a mean can be made. (Station *C*, for example, will have values observed from *A* and *B* and also values obtained from observations to *A* and *B*.) A fairly dense height control will thus be established from which the contouring may be carried out, usually by further trigonometrical levelling by single observations, to (or from) the control points, from (or to) field corners and the like.

Traversing. This is a graphic method of carrying out a traverse (see Chapter VI). It tends to be tedious and, generally, is used only along sunken roads, eroded stream beds, etc., where visibility is restricted and other methods cannot be used.

Select, and place temporary marks on, the stations it is desired to occupy on the ground and, should the starting point not be already plotted on the table, prick off an arbitrary point from which the start is to be made, say *A*, *a* (Fig. 26). Set up at *A*, level the table, and orientate by lining up on other

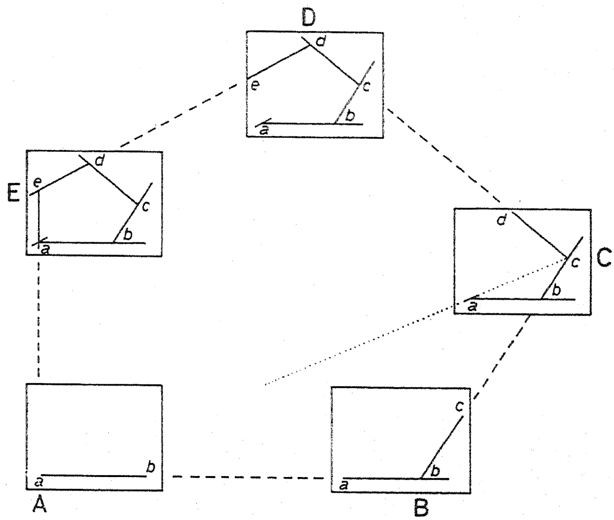

Fig. 26. PLANE-TABLE TRAVERSE.

plotted points if *A* is already plotted, otherwise orientate by trough compass. Draw in the ray to *B*; measure the distance *AB* and prick off *b*. Now set up at *B* and orientate back on *A*; draw in the ray to *C*, measure *BC* and prick off *c*. Repeat at *C*, *D*, and *E*. If opportunity occurs check with cross rays such as *CA*, *ca*. Plot the surrounding detail by radiation and intersection from each set up.

The final check is to see how nearly the traverse "closes" on the starting point *A* (or on to some other previously plotted point to which the traverse

is being run). The traverse should be adjusted graphically by the method given on p. 64.

Resection. If an observer at an unfixed point measures the angles subtended between three points whose positions are known he can compute his own position. Similarly the hydrographic surveyor finds the positions of his soundings by observing the angles subtended between three previously plotted surveying marks situated on the land. Positions thus found are *resected positions.* The hydrographic surveyor uses an instrument called a "station pointer", but the topographical surveyor may resect his position

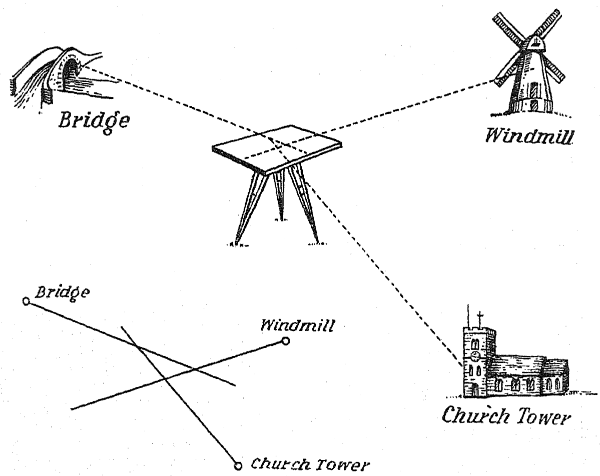

Fig. 27. RESECTION: Observer inside triangle.

equally well by drawing rays to three well selected positions which have previously been plotted on his table.

This is particularly useful when plane-tabling in an area where previously fixed control points are sparse and distant. The plane-table may be set up in the middle of nowhere and by drawing rays to three distant control points its position can be established. The problem is frequently referred to as the *three point problem.*

After setting up the table, guess its position and place the ruling edge of the alidade on the line joining this estimated position and the most

distant of the three control points. Orientate the table on this most distant point, say the church tower in Fig. 27. Clamp the table and draw in the ray from the tower and also rays from the other two selected points. Except by a lucky fluke a triangle of error, large or small, will result.

The triangle of error can be reduced to a single point by re-orientation of the table, *i.e.* by turning it either clockwise or anti-clockwise. Any turning of the table will swing all the previously drawn rays either clockwise or anti-clockwise—they can only swing the *same* way, and this fact gives the clue as to which way the table should be turned. Study of Fig. 27 shows that if all the rays are swung clockwise the triangle will be reduced in size until it becomes a point, and it can also be seen that the final position is inside the triangle. Fig. 28*a*, however, shows the more usual case where the observer is not inside the triangle made by the three control points, and is also *not* inside the triangle of error, because to reach a point inside the triangle rays from *A* and *C* would have to be swung clockwise but the ray from *B* would have to swing anti-clockwise. After a little experience and provided the first triangle is not too big the correct position can usually be found by inspection if the following rules are followed:

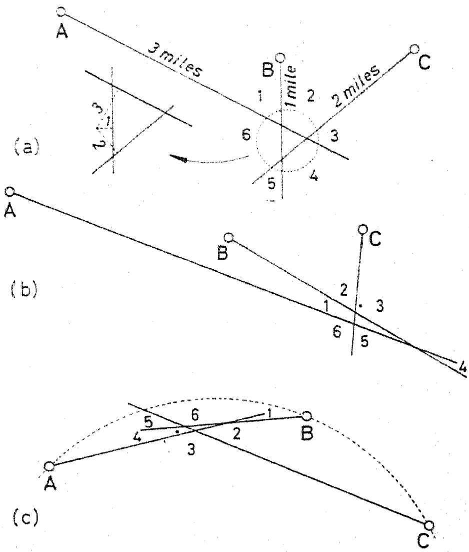

Fig. 28. RESECTION: Observer outside triangle; the dot shows true position.

(1) The observer's position is inside the triangle of error only when it is inside the triangle formed by the observed objects.

(2) When the position of the set up is not inside the triangle of the three control points the true position will always be in sectors 3 or 6, as numbered in Fig. 28, and will be on the same side of the ray to the most distant point as the intersection of the other two rays.

(3) The perpendicular distances of the true position from each ray will be proportional to the distances from the set up to the stations observed.

[NOTE.—Rule (2) breaks down in the somewhat rare case when the position, *P*, lies within one of the segments formed by the three points and the circumscribing circle drawn through them (Fig. 28*c*)].

Following these rules a revised position is selected from the triangle of error and marked with a pencil dot. The alidade is laid on the line joining this dot and the most distant station, the table is unclamped and re-orientated

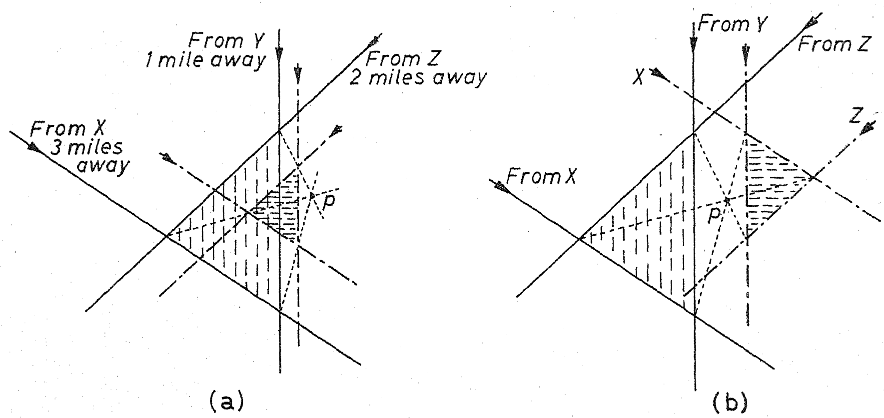

Fig. 29.

on this distant station. The resecting rays are again drawn and will result either in a perfect intersection or in another (but usually) smaller triangle of error, of the same shape if the second selected position has not been moved far enough from the first drawn resecting rays (Fig. 29*a*) or "inside out" if they have been moved too far (Fig. 29*b*). In either case the true position may be found by joining (and producing, in case *a*) the corresponding apices of the two triangles of error. If observations are correct these lines will intersect in a point.

When possible the finally selected position should be checked by drawing a ray in from a fourth independent station (or well intersected point of detail).

The three point problem is insoluble when the observer is on the circumference circle drawn through the three control points. It is therefore

necessary to select the points from which the resection is to be made with care; when possible select them so that the middle point is the nearest to the set up. Further, the points should be selected so that the angle subtended, at the set up, between the two outer points should not be less than 60° (there is no harm in one angle being very small provided that the points subtending the small angle are not too close together).

The Hydrographic surveyor's station pointers mentioned on p. 52, provides a mechanical solution of the three point problem. The plane-tabler may adopt a similar method, using a sheet of transparent tracing material. Clamp the table and fasten on it a piece of tracing paper large enough to cover the three control points. Mark on it a dot, p_1, to represent the observer's position; from it rule in long rays to the control points A, B, and C. Unfasten the tracing paper and manoeuvre it over the table until the three drawn rays pass simultaneously through the plotted positions a, b, and c. Prick the dot, p_1, through on to the table. If the work has been done carefully (and the tracing paper has not distorted) this will give the true position of p, which should, however, be tested by drawing in the resecting rays as before; if a small triangle of error results, eliminate it by the process just described.

4. TECHNIQUE OF DRAWING RAYS ON THE PLANE-TABLE

Use a fairly hard pencil (nothing softer than an "H") with a sharp point. Before drawing a ray make sure that the ruling edge of the alidade is in contact with the actual plotted point on the table from, or to, which the ray is being drawn. [When a parallel arm is fitted to the alidade (see p. 44) this is not necessary; the alidade is sighted on the object and held firm and the parallel arm is then brought into contact with the plotted position of the object before the ray is drawn.] When bringing the sights of the alidade on to an object pivot it about a finger tip or the blunt end of a pencil but NEVER about the point of the pencil, or a hole will soon be torn in the paper. To avoid a superfluity of unnecessary lines on the paper draw in only that part of the ray necessary for the particular intersection, radiation, or resection being carried out; in particular, do not carry the drawn line through the previously plotted point from which a ray is being drawn or the point in question will soon be obliterated by a mass of intersecting lines. Keep the pencil vertical when drawing lines.

5. COUNTERSECTION

This name is sometimes applied to a method of fixing the position of the table which has virtually been explained under the heading of Traversing. If before leaving a set up, x, it is decided to make the next set up at an unfixed point, y, which is visible from x, draw the ray from x to y. Pace the distance to y and prick off the position of y on the drawn ray. On arrival at y, set up the table and orientate it along the reverse ray yx. The table is then ready for further work and its position is said to have been countersected from x.

CHAPTER VI

SURVEYING—III

TRAVERSING AND CHAIN SURVEYING

1. INTRODUCTORY

A traverse is a series of connected straight lines, the lengths and directions of which are all measured. Thus it involves both linear and angular measurements.

The angles may be measured with a theodolite or with a compass, giving rise to theodolite traverses or compass traverses (or they may be plotted graphically on the plane-table as described on p. 51).

The linear measurements may be made in a variety of ways with differing degrees of precision. The geodimeter and tellurometer (see p. 32) and precise taping with invar tapes supported on tripods, are used for the precise traverses which sometimes take the place of triangulation (see p. 32). Surface taping and chaining are much used for "detail" traverses between known points, *i.e.* for plotting the detail between tertiary triangulation stations situated a mile or so apart. For less accurate work pacing may be used, *i.e.* counting one's paces when walking from point to point, either mentally or mechanically by a passometer, which measures paces, or pedometer, which does the same thing but records them as distances (see Figs. 30 and 31). If the ground is smooth enough a cyclometer may be used. Finally, the distances may be measured optically by tacheometric methods (see p. 43). (This is now much used for fixing detail on large-scale maps especially since the introduction of instruments known as "self-reducing tacheometers".)

The purpose of the survey will determine the type of traverse required and the following factors will influence the choice of equipment: (1) with quite a small modern theodolite angles can be read to 20″ of arc, whereas it is optimistic to expect an accuracy much better than $\frac{1}{2}°$ (= 1,800″) with an ordinary prismatic compass. On the other hand, the compass is a pocket instrument and may be carried all day without fatigue; (2) compass

traverses with pacing may be used instead of the plane-table for fixing the detail of a map, provided the control points are fairly close together, the

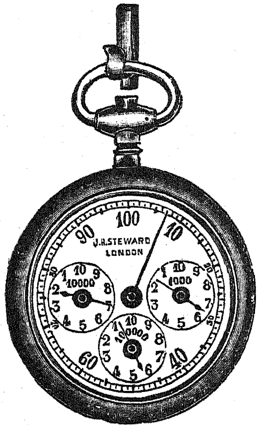

Fig. 30. PASSOMETER.

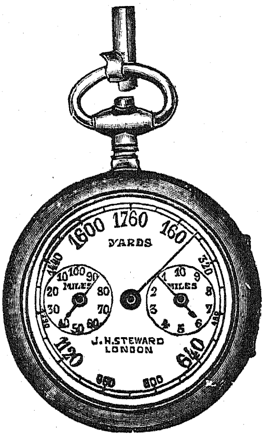

Fig. 31. PEDOMETER.

equipment being much more portable. This type of traverse and its equipment will be described.

2. THE PRISMATIC COMPASS

The prismatic compass is a circular magnetic compass which has, on one side a prism, *P*, with a slit in it, and on the opposite side a sight vane, *S*, with a vertical hair. The plane containing the prism slit and the sight vane hair also contains the pivot of the compass card, the central point of the compass, *C*. The prism reflects the figures of the card immediately below it and enables the surveyor to read the bearing without taking his eye from the sights and the object being sighted. (Because the figures read by the prism are on the eye side instead of on the object side of the compass they have to be 180° out of step, with 0° printed against the south point and 180° against the north point.)

There are several types of prismatic compass, a common variant from the type shown in Fig. 32 is one with a hinged glass lid with a line scribed down it instead of the sight vane, *S*.

To take a bearing the sight vane and the prism, which is on a hinge, must be lifted to the positions shown in Fig. 32. The act of lifting the front sight (or the lid) usually releases the compass card and allows it to revolve freely. The compass is lifted to the eye and sighted on the object whose bearing is required, with the hair (or scribed line) of the front sight midway between the sides of the prism holder. The figure on the compass card corresponding to the required bearing will be seen reflected in the prism. (See p. 100 for an explanation of "bearing".) Both hands should be used so that the compass may be held steady, the finger of one hand being held close to the check stop so that the card may be steadied if it is swinging too violently. But the check stop *must* be free when the actual reading is made.

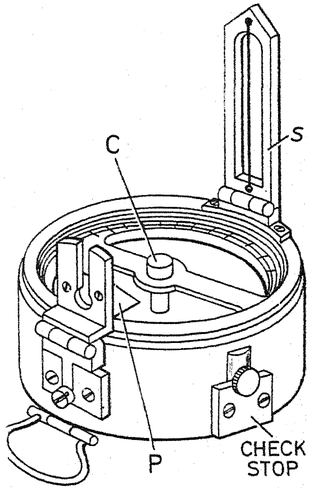

Fig. 32.

Simple as this procedure is, some elementary precautions must be taken: (1) all magnetic material should be removed from the pockets before the bearing is taken; (2) the bearing should not be observed from a position close to strongly magnetic material such as a corrugated iron shed or railway lines; (3) the compass must be held horizontally so that the edge of the card does not rub against the top of the compass; (4) to accord with the surveying principle of independent checks, the "back" bearing should be taken from the other end of the line, and should differ from the "on" bearing by exactly 180°.

Some prismatic compasses are "liquid". In these the compass is filled with a non-freezable liquid, so that the compass card is completely immersed. In consequence the card comes to rest more quickly and remains much more steady than the card of the non-liquid type. If the compass (liquid or dry card) is used on a stand bearings can be taken with greater accuracy.

3. MAKING A COMPASS TRAVERSE

Compass traverses may be conducted in two ways, either the work may be plotted on a board by protractor and scale as it proceeds, or the observations

can be recorded in a **field book** and, later, plotted indoors at the end of the day. The former is the safer way; when the work is plotted as it proceeds there is little danger of important observations, *e.g.* "shots" to important points being omitted; on the other hand, one of the great advantages of the traverse method—the portability of the equipment—will have been lost. If drawing board, scale, and protractor are to be carried it would be better to go one step farther and use a plane-table, as described in the last chapter.

Any ordinary note-book can be used as a field book, long pages (with the hinge on the short side) are an advantage, and good paper which will not tear easily when wet is essential. Parallel lines, at least half an inch apart, should be ruled down the middle of each page. (Note, such field books or surveyors' note-books may be purchased with the rulings printed in them.) This double line actually represents the line traversed by the surveyor; distances and bearings of the traverse line are recorded within the rulings whereas information regarding the detail on either side of the traverse line is placed on the corresponding side of the field book page. For this reason it is customary to start the booking at the bottom of the page and work upwards.

Most traverses are of the "closed" variety, *i.e.* they start at a known point and they "close" on to another known point or return back to the starting point. When making a traverse it usually pays to walk over the route first and select and mark, in any convenient temporary way, the traverse stations, *i.e.* the corners where the traverse will change direction. A very rough rule is that the longer the legs and consequently the fewer the changes in direction, the more accurate will the traverse be. It is, of course, essential that there should be uninterrupted visibility between one traverse station and the next and it is equally important that linear measurement shall be easy and consequently exact; *e.g.* it is unlikely that a traverse leg which crossed a stream and several close hedges could be paced with any semblance of accuracy.

The stations should be given letters or numbers and whenever they have to be referred to this letter or number should be used: endless confusion ensues if a station is referred to as, say, *C* in one entry in the field book and as, say, "signpost" in the next. Generally speaking, letters are less confusing than numbers, but this is a matter of individual choice. When numbers are used it is a wise precaution to surround them with a triangle

when entering them in the field book to avoid any chance of their being mistaken for bearings or distances.

When the stations have been marked the measurement can start. Stand at the first station and take a bearing to the next; enter the name of the observing station and the "on" bearing inside the ruled lines. Take bearings to points of detail (these are known as "side shots") and pace the distance to those that are reasonably close. Now start pacing to the next station; whenever points of detail are seen which should be plotted, stop pacing and enter the distance paced within the lines of the field book but book the bearing of the side shot and the description of what is being observed outside the lines; continue thus until the next station is reached. Book the completed length of the traverse leg and circle it round. Next take a "back" bearing to the first station and book it and, if it agrees to within $\frac{1}{2}°$ of the corresponding "on" bearing tick it as being correct and also underline the "on" bearing.[1] Then start the new leg, first observing the "on" bearing and then pacing, as before. A specimen booking is shown in Fig. 33*a*.

Two special precautions must be taken when carrying out the above procedure: (1) if one of the stations has had to be made near magnetic material do not observe the bearing from there but move twenty yards or so along the leg before observing; (2) every point of detail to be plotted by intersection needs two widely separated bearings, *i.e.* ones that intersect at an angle of not less than 40°, *e.g.* in Fig. 33*a*, at 120 yd on the first leg the bearing of the cottage was 025°, at 240 yd it was 355°, which means that the two bearings intersect at only 30° apart; this is too acute, so a third bearing is taken from *B* station to give a wider separation.

Notes and small sketches should be made in the margins of the field book to assist in subsequent plotting. Take plenty of room over the booking and if there is much detail to record use a new page for each new leg. Date each page of the book. It cannot be stressed too much how important it is to record the date the survey is made.

[1] Underlining the bearings and encircling the lengths of the legs greatly assists the plotting of the main traverse by making the essential measurements stand out amongst the numerous bearings and distances recorded.

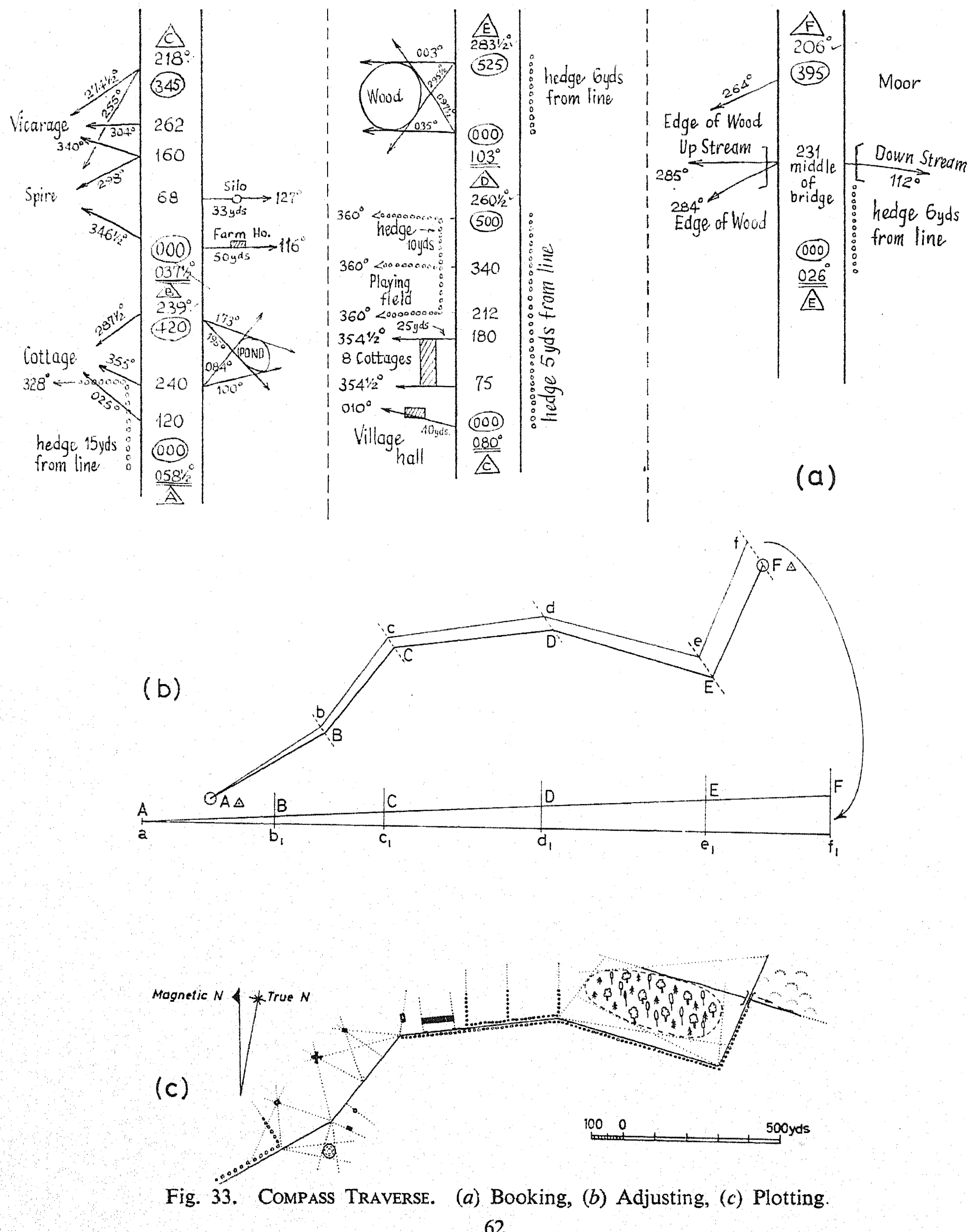

Fig. 33. COMPASS TRAVERSE. (*a*) Booking, (*b*) Adjusting, (*c*) Plotting.

4 (a). PLOTTING THE TRAVERSE FROM THE FIELD BOOK

As for all other survey drawing, good paper should be used. Very lightly ruled squared paper with wide rulings (no closer than 5 or 4 to the in.) is handy for plotting compass traverses but, if not available, the drawing paper should be lightly ruled, in one direction only, with parallel lines about an inch apart; these rulings will represent magnetic meridians and will greatly assist in the plotting of the bearings.

The starting point for the plot must be placed on the paper in such a position that the whole traverse will fit on the paper, *e.g.* if the general trend of the traverse was to the south-east the plotting should be started somewhere near the top left corner of the paper. If the traverse has been run to another known point this finishing point should then be plotted either by bearing and distance from the starting point, or by its rectangular coordinates, given as so many feet east and so many feet north of the starting point (west and south are referred to as -east and -north). It must be remembered that such a bearing or coordinate, if obtained from official survey sources, will be referred to the coordinate or grid meridian and not to the magnetic meridian. The angular difference between these meridians will be found printed on the official maps containing the area. It varies from place to place (and from year to year) but, in this country the grid meridian is (1963) about 10° to the right of the magnetic meridian.

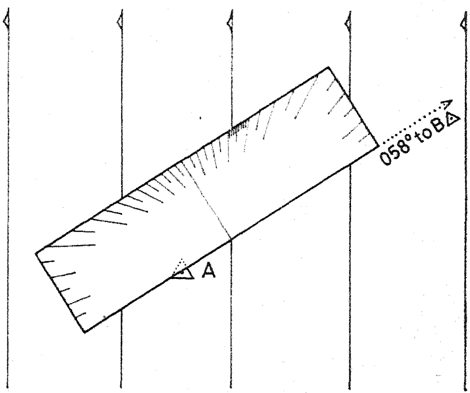

Fig. 34.

When the starting and finishing points of the traverse have been plotted lay off the first bearing from the starting point, using one of the ruled magnetic meridians as a reference line. A rectangular protractor will be found more convenient for this than the semi-circular type; place the centre of the radiating graduations on the nearest meridian and turn the protractor until the appropriate graduation is cut by the meridian, then slide the protractor

up, or down, the meridian until one edge touches the starting point. The bearing is then ruled in, as shown in Fig. 34. Prick off the appropriate distance, according to scale, of the next station. Do not yet tick off the intermediate points along the traverse leg from which side shots were observed because, if the traverse has to be "adjusted", all this work will have to be done again.

Continue plotting the main traverse until the end when, if the measurements have been made without error, the finishing point will have been reached.

4 (b). ADJUSTMENT OF TRAVERSE

Seldom will the plot of a traverse finish exactly on the known finishing point (as stated above, often this is the starting point) and it must be adjusted to do so. The method is simple and can be seen clearly on Fig. 33*b* in which the traverse has been plotted as $A\ b\ c\ d\ e\ f$ but the true finishing point should have been F. Ff is the "closing error" and its magnitude and direction may be measured from the plot; however, for the graphical solution these measurements are not required. Join Ff and draw short parallels to Ff through every traverse station; each station, in turn, will be adjusted along these short parallels. To find the distance each station should be moved, construct a base line $a\ f_1$, to represent the whole measured traverse, and on it tick off b_1, c_1, d_1, and e_1, so that the lengths a_1b_1, b_1c_1, c_1d_1, etc., correspond to the lengths measured on the ground. In Fig. 33*b* these lengths have been made equal to the legs of the plotted traverse but it will usually be found more convenient to draw them to a smaller scale, say, half that of the plotted traverse. On this base line erect short perpendiculars from b_1, c_1, d_1, e_1, and f_1, and on the one drawn from f_1 lay off the distance fF, the mis-closure shown on the plotted traverse; join F to a, and label the points where the line intersects the short perpendiculars as E, D, C, and B. The short intercepted lengths b_1B, c_1C, d_1D, etc., are the distances that each station must be moved along its parallel; transfer these distances with dividers and join these new points $A\ B\ C\ D\ E\ F$ to represent the adjusted traverse.

4 (c). PLOTTING THE TRAVERSE (Continued)

The detail and side shots must now be plotted on the adjusted traverse. Referring to the field book, plot the intermediate points from which side

shots were observed, according to scale, along each traverse leg. (Note, the adjusted traverse legs may well be a little longer or a little shorter than the legs as first plotted and small local adjustment may be necessary when plotting these intermediate points, but such adjustment is usually small.) Plot the side shots and when intersected points have been plotted draw in the detail between them. When "cocked hats" (triangles of error) occur select a position within the triangle so that the perpendicular distance from the selected position to the drawn bearing is roughly proportional to the distance from the point at which the bearing was observed. Many of the unimportant points of detail will have only two intersecting bearings and, with these, no adjustment can be made. Figs. 33*a* and 33*c* show the field book and the traverse plotted from it.

Practice in this type of work may be obtained by drawing an imagined map on squared paper of, say, a country lane with a little detail (cottages, woods, streams, etc.) on it. "Run" a pencil traverse along the lane and, then with a protractor, take off the bearings of the various points of detail along the route and fill in the field book accordingly. (Figs. 33*a* and 33*c* were constructed in this way.)

5. THEODOLITE TRAVERSES

In theodolite traverses the directions are obtained by theodolite by measuring, at a traverse station, the angle between the back station and the fore station. By applying this angle to the previous "back" bearing the new "on" bearing is found. It follows that for the proper orientation of the traverse, the bearing of at least one of the traverse legs must be known; but this one bearing will, in theory, suffice for the whole traverse (in practice, the bearings of other legs are checked, by one means or another, during the course of the traverse). Theodolite traverses are adjusted in the same way as compass traverses, except that the misclosures (being smaller) are usually computed instead of being found graphically.

6. CHAIN SURVEYING

Probably the oldest form of surveying land (used, it is thought, by the ancient Egyptians after the annual flooding of the Nile valley) is by a method known as **chain surveying.**

Chain surveying makes use of linear measurement only and, in consequence, the barest minimum of equipment is required. It is eminently suitable for the surveys of comparatively small areas on ground that offers little obstruction to linear measurement. It is very useful to the farmer surveying the areas of his fields or making a map of his whole farm; but it is not a suitable method to adopt in built-up, or heavily wooded, areas where visibility is obstructed and long straight linear measurement is impossible.

The method is named after the chain, a simple and tough piece of measuring equipment, though not a very accurate one. The chain has 100 links, each shaped rather like a dumb-bell, connected one to another by three small links. Chains are of two sorts, the engineer's chain 100 ft long or the Gunter chain (named after its inventor, Edmund Gunter, 1581-1626) of 66 ft. The latter is frequently used by agriculturists because, by its aid, acreages are so easily calculated—ten square chains being equal to one acre. It is, however, rather heavy and cumbersome and most "chain" surveys these days are measured with tapes or steel bands.

Auxiliary equipment needed are ranging poles for marking stations or aligning the line to be measured, and "chain arrows", large skewer-like pegs, usually supplied in bundles of ten, which are used to mark the ends of complete chain or tape lengths. Some form of equipment for measuring a right angle (the only angular measurement needed by the method) is useful but not essential.

Chain surveys are built up of a series of triangles, of which, the side lengths and not the angles are measured. The framework thus made is usually referred to as a triangulation, though in modern surveying phraseology, it should be known as trilateration.

The simplest chain survey would be one of a triangular field, where one triangle would supply all the triangulated framework necessary (Fig. 35*a*). However, most surveys are generally of a roughly rectangular pattern in which two triangles are necessary, one on either side of a common diagonal (Fig. 35*b*). To conform to the principle of independent checks the opposite diagonal will also always be measured. The survey of a complete farm will usually be of a more complex pattern and more than two triangles will be required (Fig. 35*c*). Generally a long "back bone" will be sought on which triangles to right and left may be "hung".

Topographical detail is picked up from the survey lines which should be run as close to the detail as possible. Should there be no survey line in the near vicinity of important detail a special "detail" line must be measured, *e.g.* the stream running roughly east and west in Fig. 35*c* would need a detail line run from x on the back bone to y on one of the main lines.

The detail is picked up by two methods, (1) **perpendicular offsets**, in which an imaginary perpendicular is dropped from the point of detail on

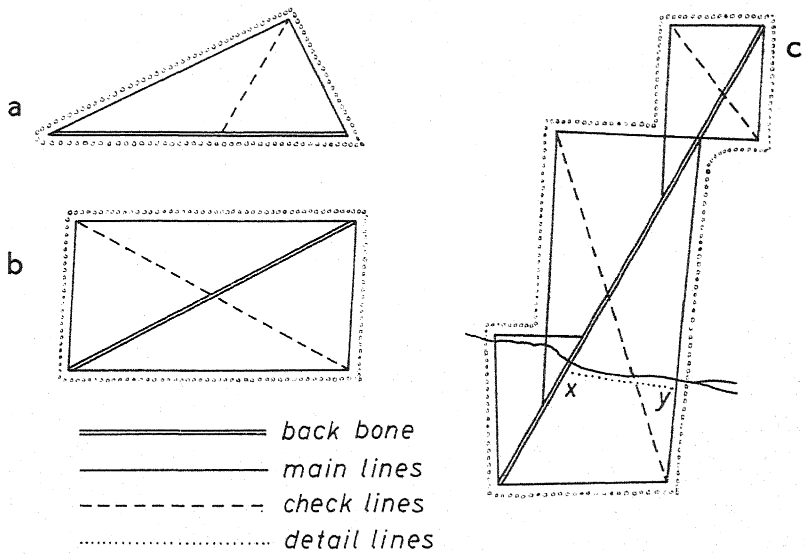

Fig. 35.

to the survey line; the measurement on the survey line of the foot of this perpendicular is noted and also the perpendicular distance, the "offset" (Fig. 36*a*), and (2) **tie lines**, in which the tie line measurements between the point of detail and suitable points on the survey line are made (Fig. 36*b*).

As a general rule and particularly when the right angles have to be guessed, perpendicular offsets should not exceed 30 ft; when the detail is more than this distance from the survey line, the tie line method should be used. The accuracy of the tie line method depends on the value of the

receiving angle; the nearer this is to 90° the more accurate is the fixation of the detail—the angle need not be measured, but it should not be less than 40° or greater than 140°.

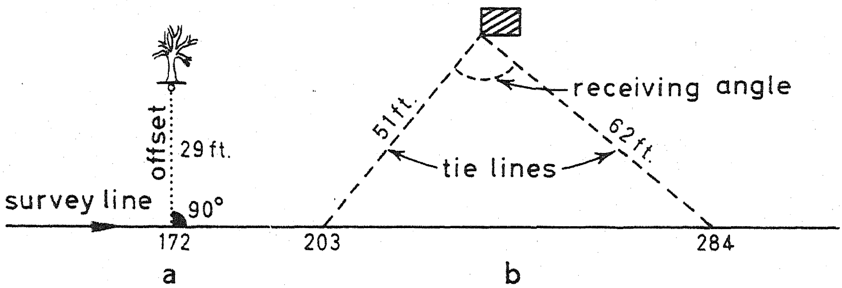

Fig. 36.

When making a chain survey, first walk round the area and select positions for the stations, having the following in mind when making the selection:

(i) Adjacent stations should be intervisible. This is not essential (the experienced surveyor has methods of straight chaining between points which are not in sight of one another) but it is highly desirable.

(ii) Easy chaining between stations is essential if accurate work is to be carried out. A line that ran for much of its length along the top of a thorn hedge could not be measured accurately.

(iii) Main lines should be as few as practicable and should be so sited that they can pick up as much detail as possible (thus avoiding superfluous detail lines).

(iv) Main triangles should be "well-conditioned". In general this means that the triangles should not contain very acute or very obtuse angles (but when one of the angles is approximately 90° there will be no harm in having one of the other angles very acute).

(v) The triangulation should cover the whole survey. This may be construed as—no part of the survey should lie more than thirty feet outside the triangulated framework.

When the stations have been selected they should be marked with poles. Intersections of lines should also be marked. Measurement may now start.

Two people are required for the measurement, the **leader** and the **follower**, who is in charge of the measurement. The follower holds his end of the chain or tape against the pole from which the measurement is being made and directs the leader, who carries the other end of the chain and also a ranging pole and ten arrows, on to the correct line to the next station. For this direction the leader holds his pole at about the 99 ft mark, and moves it right or left until the follower is satisfied that it is on the correct line, when it is so the leader sticks it into the ground. The leader now tautens the chain (or tape) so that it just touches the pole; he then sticks his first arrow into the ground at the 100 ft mark (with a chain or steel band this will be the flat of the handle, with a tape it will be the 100 ft graduation). If any offsets or tie lines have to be measured from that chain length, the chain is left lying on the ground until they have been made. When this has been done the leader drags the chain forward until the follower has reached the first arrow left behind by the leader. The follower now holds his end of the chain against this arrow and directs the leader on to the correct line, as above. The same procedure as before is carried out and the second arrow is stuck into the ground. On moving forward the second time, however, the follower picks up the first arrow and carries it along with him—and so on. This procedure prevents unmeasured gaps in the line and also, by the number of arrows held by the follower, it is possible to tell at a glance the number of complete chain lengths that have been measured, *e.g.* if at the end of the measurement the last odd length is 67 ft and the follower, having picked up the last arrow (this is easily forgotten) has seven arrows in his hand, then the whole measurement was 767 ft. A check must always be made by seeing that the leader has the right number of arrows (in this case, three) left in his hand.

Should sloping ground, of a gradient steeper than about 1 : 12 be encountered "stepping", as shown in Fig. 37*a*, must be used. Whoever is at the lower end of the slope holds the chain as nearly horizontal as he can with his end against a ranging pole held vertically. When the chain is taut the pole is stuck into the ground and marks the point which is 100 horizontal feet from the other end. A chain arrow is substituted for the pole and the

measurement proceeds. (Note, it is much easier to chain downhill than uphill.)

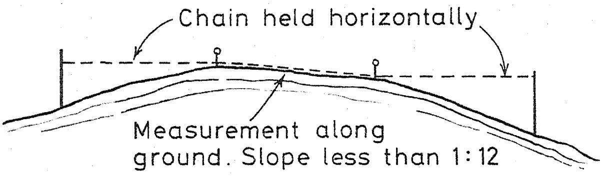

Fig. 37*a*. CHAINING ON SLOPING GROUND.

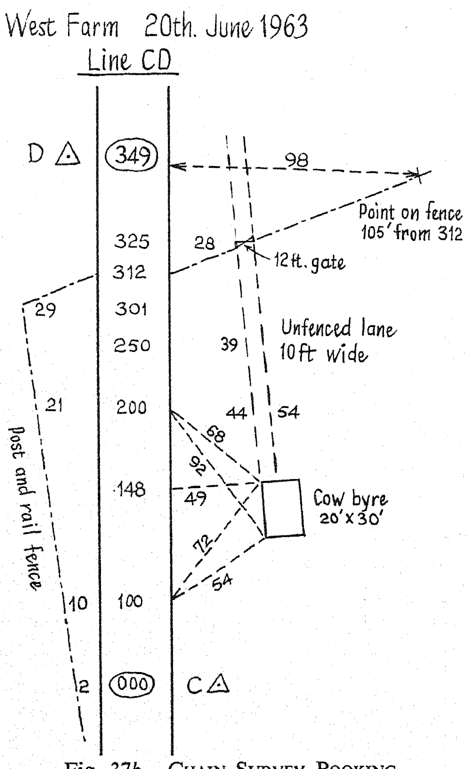

Fig. 37*b*. CHAIN SURVEY BOOKING.

The booking is very similar to that of a compass traverse. Double lines down the middle of the page represent the chain line and all bookings

referring to distances measured on the chain line are made within the rulings. Booking is done up the page so that detail situated to the right of the line is booked on the right, and *vice versa*. Readings on the chain from which offsets or tie lines were measured are booked within the lines but the offsets and the tie lines themselves are recorded in the margins. The last measurement recording the total length of the line is always encircled (see footnote on p. 61). No attempt is made to keep the booking to scale—when there is no detail to record the scale is kept small, when there is much the scale is made large so that the detail may be clearly booked. The measuring starts at zero again for each new line. Fig. 37*b* shows a typical booking, in which two things should be specially noted: (i) for perpendicular offsets the measuring lines are not shown, but for tie lines they are; (ii) any straight feature which crosses the chain line must be staggered in the booking, so that it leaves the chain line at the same chainage as it entered. (See the fence crossing the chain line at 312 ft in Fig. 37*b*.) Two different methods are shown for booking offsets to a parallel sided feature such as a road.

CHAPTER VII

THE USE OF AERIAL PHOTOGRAPHY IN SURVEY AND MAP MAKING

Photographs taken from aircraft are now widely used in map making and in survey. Among the many different purposes for which these photographs are taken are: (*a*) the confirmation of details of land survey; (*b*) the preliminary mapping of regions which will ultimately be surveyed in detail from the ground; (*c*) the rapid survey of little known or inaccessible regions, where air photos can be used to map, with reasonable accuracy, large areas of difficult terrain in a fraction of the time taken by field parties. The precision of modern equipment, cameras, and plotting apparatus, is such that levels can be measured to an accuracy of a foot from photos taken at 6,000 ft. Lower flying heights give a still greater accuracy.

The preparation of topographical maps is not the only purpose for which accurate photography is needed. The accurate plotting of structural features is obviously of prime importance to those who seek to exploit mineral resources of a region. The recording of vegetation and forms of land-use helps to indicate, say, the effects of soil erosion, or the suitability of an area for a particular type of lumbering operation. More precise "targets" for the air photographer may be the site of new towns, or dams, or factories.

1. VERTICAL PHOTOGRAPHY

Vertical photographs are usually required for map-making purposes—though obliques are frequently taken in conjunction with these to enable various details of the region to be recorded; while for large-scale work ground methods may have to be used where obstacles (such as trees) mask detail beneath.

Fig. 38 shows how the aircraft takes a continuous series of vertical photographs by means of a camera set to record the details immediately below at short-timed intervals. The area to be recorded is covered by a

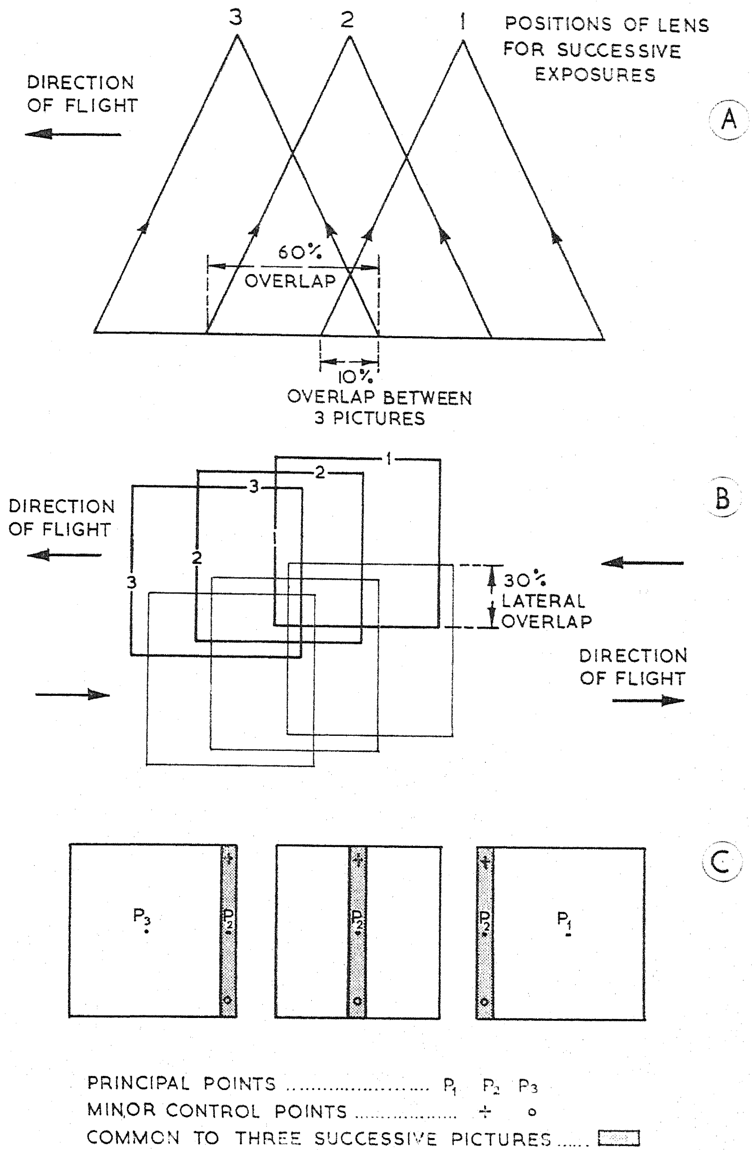

Fig. 38. Vertical Air Photographs.

(*a*) Shows the overlap necessary in the continuous series of vertical photographs; (*b*) shows the lateral overlap required; (*c*) the ten per cent. common to three successive photos, and points used in plotting.

series of parallel strips of photographs arranged so that each overlaps its neighbour by 25-30 per cent. The timing is such that there is a 60 per cent. forward and 30 per cent. lateral overlap of the photographs. The ground is thus photographed from two slightly different positions which allows a three-dimensional or stereoscopic study from any two consecutive photos. This technique is also necessary because there is likely to be distortion near

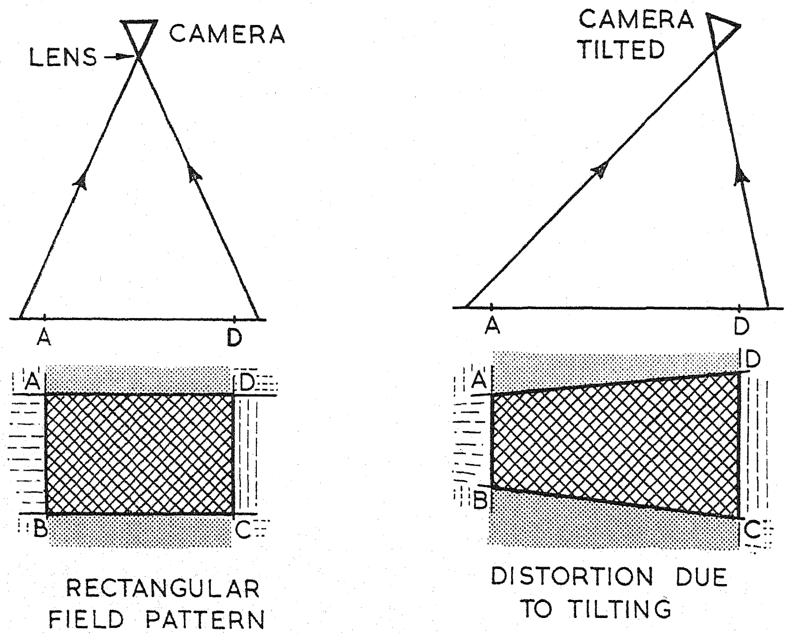

Fig. 39. Distortion Produced in an Air Photo when the Camera is Tilted. A source of error, therefore, in vertical photographs of steeply-sloping country.

the edges of the photos, due to a combination of errors of tilt and height (Fig. 39). Such distortion can be rectified only by dividing the area into many different planes and rectifying for each separately.

To obtain a composite picture of an area, showing, of course, a greater wealth of detail than the drawn map, it is necessary to assemble a *mosaic* by assembling the vertical photos to form a continuous picture of the ground,

matching the detail from picture to picture. To construct line or plannimetric maps special methods of plotting must be used.

2. PLOTTING FROM AIR PHOTOGRAPHS

By using the principle of triangulation (see Chapter IV).—Where tilts are below 4° and the relief not greater than a tenth of the mean height of the aircraft above the ground, plots can be made from vertical air photographs if the overlap principle is applied. It is possible to determine accurately a *principal point* on each photograph; this is located by means of an intersection of lines joining what are called the *fiducial marks* (marks engraved on the plate carrier and automatically recorded on the negative). The principal point is directly opposite the mid-point (optical centre) of the camera lens. The series of photos are laid out so that the lines joining their principal points are correctly aligned with the direction of flight of the aircraft. On one of the photos to be plotted two easily identified objects, such as a track junction or small tree, are selected, one on either side of the principal point. The overlapping photos on either side (60 per cent. overlap) will have an area of 10 per cent. common to *each* of these three photos (Fig. 38). A transparent plot sheet is placed above them and the angles from the objects selected (known as *minor control points*) to each of the principal points of the three overlapping photos can be determined in turn. *Ground control points* can also be established and used in plotting—these are usually located at some distance from the line of flight. By using the principle of triangulation a series of chosen points can then be accurately recorded on the plot sheet to cover the whole mosaic. Detail can be added, if necessary, by reference to the photos, or from other sources.

THE SLOTTED TEMPLATE METHOD.—A method known as the slotted template method is used to make the plotting easier. In this the rays from the principal points to the control points are replaced by slots cut in templates prepared for each photograph. The position of the principal and control points are pricked through, circled, and marked on the template, and a hole punched over the exact position of the principle point. This hole is fitted on to a stud in a cutting machine, and a longitudinal slot of the same width as the stud is cut from this stud to the control points. Similar studs, with a fine hole through the centre, are then put through the slots on to the

control points. Adjacent templates are prepared and each fitted exactly over the appropriate studs. The position of each point is then transferred to a prepared "floor" beneath by gently hammering a fine steel point through the vertical hole in the stud. When the templates are removed the pattern of these points can be scaled off or transferred to transparent sheets. Again, detail can be filled in by tracings or copyings from the photographs (if small adjustments for scale are made) or from other observations.

THE USE OF MACHINES.—There are various plotting machines used. Instruments which can reconstruct the true spacial conditions of any pair of photographs are, of course, necessary where the relief of the terrain is outstanding and where heights and contours are required. Some stereo-plotting machines are used to draw the maps from the detail shown on diapositives (positive transparencies prepared on optically flat glass in the laboratories). The diapositives are mounted in pairs in the plotting machine and ground control data fed in; these have usually been measured by ground survey teams for selected points and are used to correct for scale and tilt.

3. DETAIL FROM AIR PHOTOGRAPHS

The value of the intelligent observation of contrasting tones on air photographs cannot be too highly stressed. This is obvious in Fig. 40 and Plate II. Here the forms of land-use are clearly illustrated. Some knowledge of the types of natural vegetation and crops grown is essential, of course, and these facts can be observed on the ground, but the air photo itself shows the pattern formed by the types of vegetation and a reconnaissance survey based upon such photos can form a reliable basis for planning the pattern of settlement and agricultural practice.

Features of past occupation can be observed in surprising detail even after traces of such occupation have ceased to be visible at ground level for hundreds, and sometimes, thousands of years. Where the foundations of buildings or the lines of a ditch or rampart once were, the soil characteristics remain different from those of the adjacent land, and subsequent vegetation or crops grown in those places have a different appearance. Hence observations from the air, whence differences of tones are more apparent, reveal the line of these ancient features of occupation, and vertical

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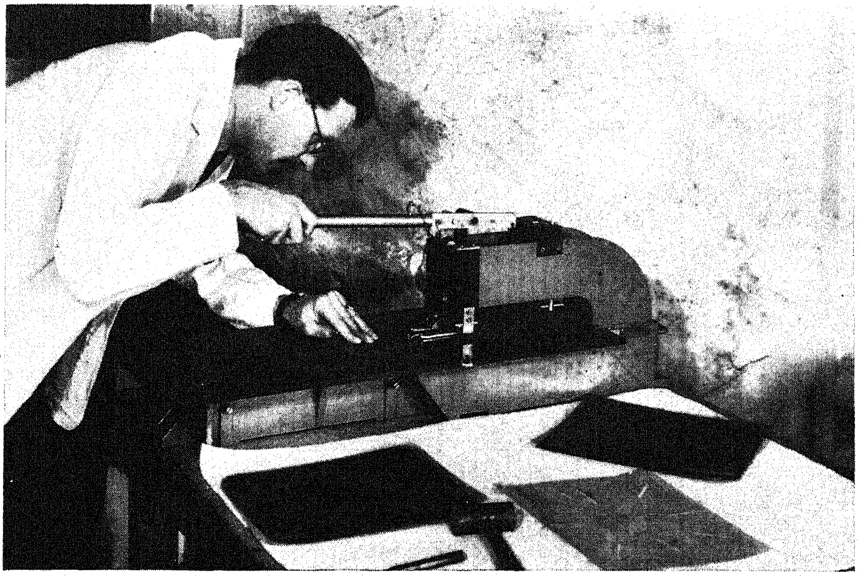
A wealth of detail can be inserted on a map or model with the aid of air photographs. Here a simple stereoscope placed above two consecutive exposures gives the artist a three-dimensional view to help him make an exact model reproduction.



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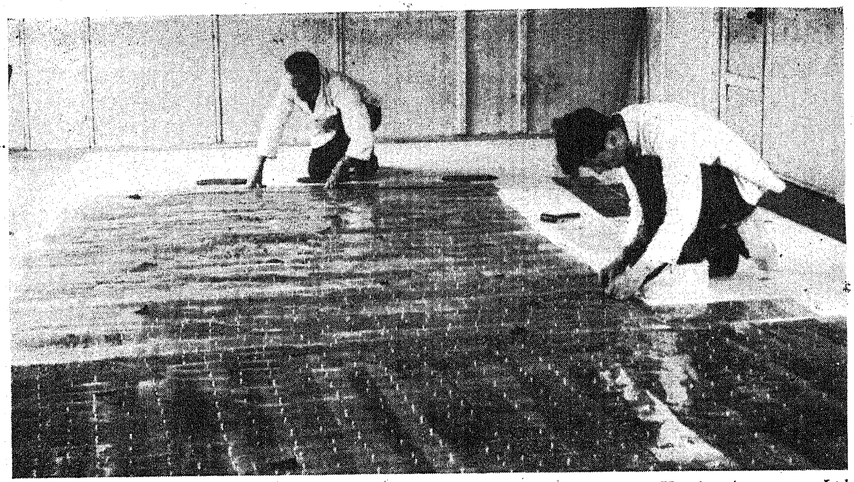
Cutting a slotted template. Notice the prepared template in the foreground.

PLATE I



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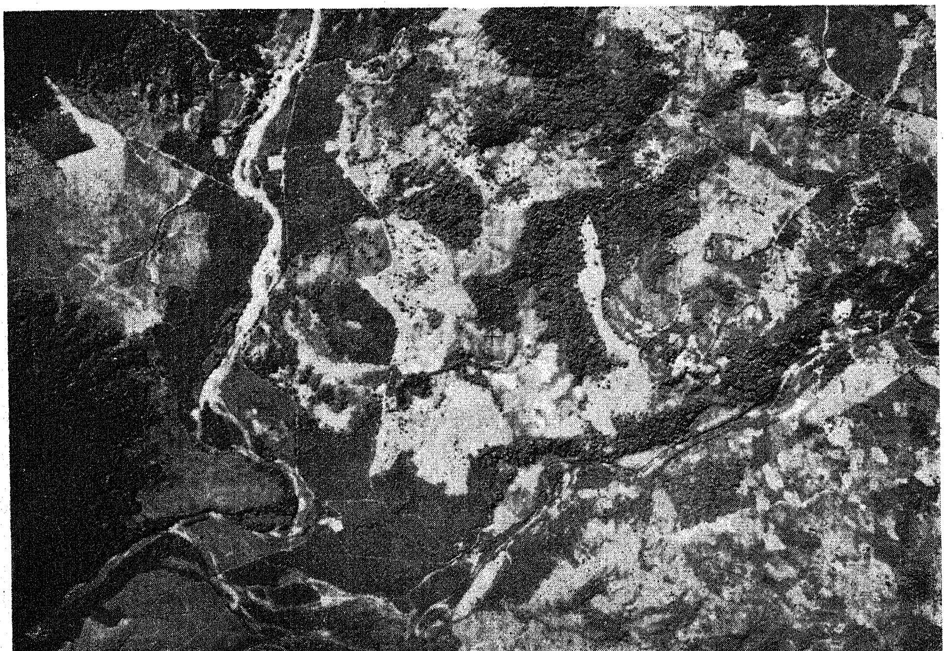
The slotted templates are being assembled on the plotting "floor". Notice the studs and the black triangles which are placed to show the position of the control points.



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Vertical air photograph from which the Land-use map shown in Fig. 40 has been prepared.

PLATE II

photographs showing such markings can be used to provide historical detail for mapping.

A World Land-use Survey, proposed by an International Geographical Congress in Lisbon in 1949, is being prepared by various national bodies, using a uniform system of classification and notation. In this aerial survey is playing a great part. It is interesting to see that the map of Cyprus,

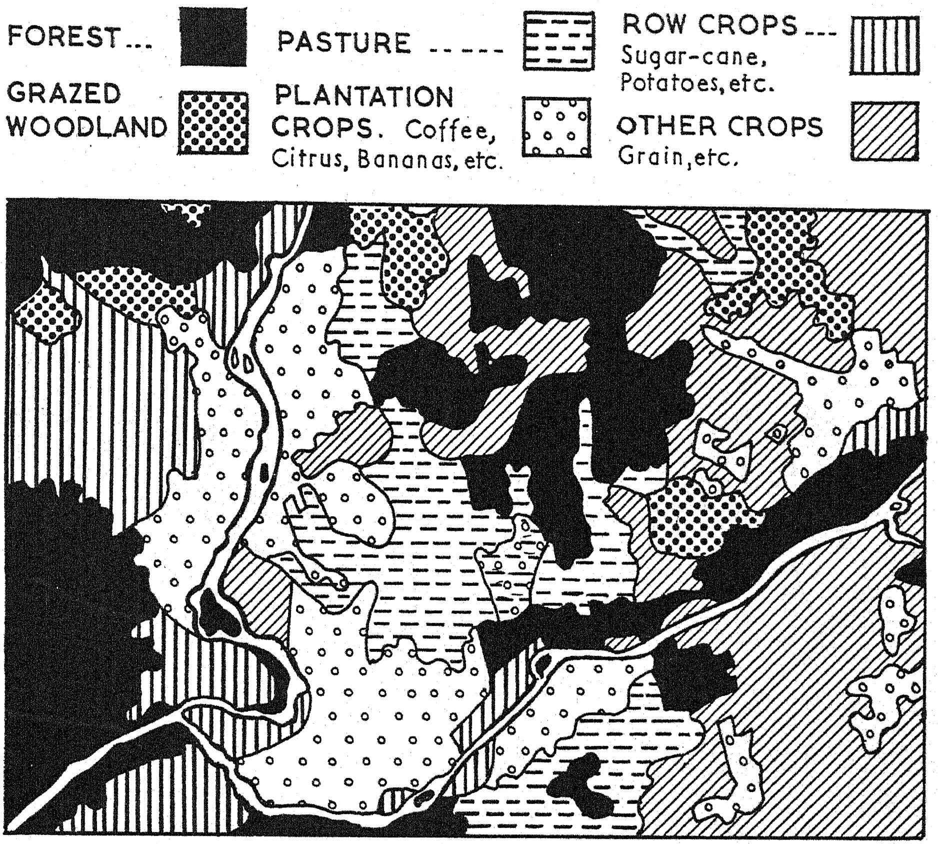


Fig. 40.

A Land-use map constructed from the air photo (Plate II), taken as part of a Land-use Survey designed to form the basis for planning tropical Settlement.

at a scale of 1 : 250,000, which was published in 1956, is based on the stereoscopic examination of 10,000 photographs (*Nature*, No. 4645, 8 Nov. 1958.)

EXERCISE II

The last few chapters deal with practical surveying as applied to map making. The best exercise after having seen, handled, and mastered the use of the various instruments, is to undertake some practical outdoor work with the instruments. Students in the Geography School of a University can normally obtain practice under expert guidance. Others must rely upon vacation courses, private help from surveyors, or upon their own resources. It is mainly for the latter that the following exercises are drawn up. To attempt them will give a concrete basis to what has been read in the various chapters.

1. Enumerate and emphasise the relative importance of the various stages necessary in the trigonometrical survey of a large area such as the British Isles.

2. A suitable base-line having been determined, describe, with illustrative sketches, the simple triangulation of an island of, say, 5,000 sq. ml. area, when the mean sea level is known, but no previously computated trigonometrical heights are available.

3. Suppose an island such as Tasmania, with about 26,000 sq. ml. area, had not been surveyed previously, and that it was desired to make a topographical survey, reasonably careful, but not of minute geodetic accuracy. The aim is to make a reliable topographical map mainly by means of careful theodolite triangulation, supplemented by plane-table work. Enumerate the various steps in such a survey and comment upon their importance.

4. As separate questions, select each of the steps enumerated in the previous answer, and describe the procedure in some detail. (A good atlas map of Tasmania will be of assistance in framing these answers.)

5. Make a list of the various instruments and accessories you would consider necessary in such a survey as that referred to in Question 3, and add brief notes why you consider each one suitable for the particular purpose in view.

6. It is desired to make, for a large-scale map of 1 : 5,000, a topographical survey of about 30 sq. ml. around a village in one of the east Pennine dales. Outline the method you would follow in such a survey, supposing that the relevant one-inch Ordnance map of the district was available. How would your map differ from the Ordnance map mentioned?

7. A tropical country has been covered by triangulation in a careful trigonometrical survey. It is desired to fill in topographical detail in (1) a wide alluvial plain watered by several rivers and mainly devoted to rice culture; (2) upland bordering the plain and rather densely forested. Explain how you would fill in topographical detail in the two regions, and for this particular purpose compare the usefulness of survey by (*a*) plane-table; (*b*) chain and staves.

8. Describe some form of prismatic compass so as to bring out the principles underlying the use of this instrument. Say how far it could be used in the survey of a small estate consisting of some woodland and three or four fields whose area varies from 5 to 10 acres.

9. Describe the essential principles of some form of clinometer and explain its use by indicating how you would contour the slopes of a rather deep and relatively narrow valley such as might be found in limestone country.

10. Describe the essentials of the Indian clinometer in comparison with clinometers of other types. Show how its advantages are apparent in the detailed topographical survey of a small stretch of hilly country where a framework of trigonometrical stations has previously been obtained by triangulation.

11. Describe, with illustrative sketch, the mapping of a park of about 100 acres, with woods at the south-west and north-east corners, and a stream, crossed by three bridges, flowing from north-west to south-east. Roads cross the park from the south and east sides. There is a lodge at the east gate, and a mansion, with chauffeur's cottage, is situated about the centre of the park. (In this answer, no *detailed* description need be given of the representation of relief.)

12. Describe how you would make a closed traverse of a path bordering the whole of the park referred to in Question 11. Say how you would adjust any errors apparent when the field-book entries were plotted.

13. Guided by the following data, describe how you would map the relief of the park referred to in Question 11. Except that in the north-east corner there is a circular knoll of about 40 yd diameter and some 65 ft above the general level of the park, the latter has no prominent relief features. Some trigonometrical heights are available, namely 268 ft the highest point of the knoll, 205 ft near the north-west, 173 ft near the south-west, and 185 ft near the south-east corner of the part in which there is a broadly uniform slope from north to south. In the lower half of its course the stream is artificially embanked some 4 ft above the surrounding level.

14. Explain, with sketches, how you would measure the altitude of a small and conveniently accessible ridge from 300 to 500 ft above a known height on surrounding land of generally uniform level. The ridge stretches from east to west, its steepest side, a regular scarp-line, being on the south and the northern side being broken by the head waters of two northward-flowing streams.

15. Describe, with sketches, the contouring of a sand dune about 60 ft above mean sea level, with the steepest side on the seaward face and the landward side fretted by minor re-entrants, the dune being relatively permanent and covered with binding vegetation.

16. Describe, with sketches, the contouring of an elliptical knoll, whose highest point is 80 ft above the known initial level, and whose major and minor axes are respectively 100 and 60 yd.

17. Describe, with sketches, the contouring of a series of four river terraces which rise from the flood-plain of a rather wide meandering river, the highest terrace being 40 ft above the general level of the flood-plain.

18. Explain, with approximate contoured sketches, how, given a topographical map such as the British one-inch Ordnance map, or the French 1 : 50,000 map you would set about determining the intervisibility of pairs of selected points on the map.

19. Describe the principle of the aneroid barometer, and explain under what circumstances, and how, you would use it to ascertain height of land in a newly explored country.

20. Since the preparation of the last edition of a certain sheet of the Ordnance Survey six-inch map, a considerable area of what was once agricultural and market-gardening land has been devoted to town-planning on "garden suburb" lines. How would you bring the map up to date to show the new houses and streets, and what instruments would you require? Give reasons for choice of such instruments.

21. Describe the work you would do with prismatic compass, Gunter's chain, and clinometer during a few days' traverse of field boundaries and roads in a lowland such as the Fen country. Illustrate by specimens of field-book entries.

22. Plot the above field-book entries and say how you would adjust any possible errors.

23. If the work indicated in Question 21 was done around villages of the Lincolnshire or Yorkshire Wolds, how would it differ from that undertaken in the Fenland? Give specimen field-book entries and plot them.

24. Describe how you would prepare the plan of a small village, with village green and with dwellings grouped around cross-roads. Give reasons for choice of instruments you would use, and illustrate by rough sketch of what the plan might be like.

25. How does the exploratory survey for an explorer's route map differ from that of good topographical survey? Suggest suitable instruments for an exploring party whose time is limited and whose facilities for transport are not good, supposing they are engaged in the survey of a tropical island such as New Guinea.

26. Give illustrative sketches to show the type of work which might result from methods noted in the preceding question.

27. What methods would you adopt and what instruments would you use in a property survey to check the plans of an estate? How and why does such a survey differ from topographical surveying?

28. It is desired to install telegraph lines through a belt of undeveloped country some 60 ml. long by 20 ml. broad, lines being required for both longitudinal and transverse directions. A range of wooded hills, whose highest points exceed 2,000 ft, extends through the centre of the longest part of the region, the remainder of which is open grassland. Describe a simple method of survey which will produce a map sufficiently accurate for use of the telegraph engineers, and give reasons for choice of the instruments you would suggest.

29. Draw a sketch to represent a map which might result from such a survey, and note its limitations.

30. Describe how you would set about a rough determination of the relative heights of the salient features in an unexplored area of contrasted relief.

31. *B* and *C* are points known on the ground and approximately south-west and south-east of another known point, *A*. If these three points have been plotted on a plane-table, and if their heights are known, explain (1) how a point roughly south of *A*, south-east of *B*, south-west of *C* can be plotted on the plane-table; (2) how the height of this point can be ascertained.

32. Describe how to set up a transit theodolite over an indicated station, *Y*, so as to read the angle *XYZ* between two other stations, *X* and *Z*, both "face-right" and "face-left". Show how you would record entries in the angle-book.

33. Describe how to make, on a scale of 1 : 15,840, a contoured map of about 4 sq. ml. of upland of the "Downs" type, if three well-distributed trigonometrical stations visible from all parts of the region are plotted on your paper and if their levels have been ascertained during triangulation. You are allowed the use of plane-table and Indian clinometer and must fix your additional stations by resection.

CHAPTER VIII

PRELIMINARIES TO MAP READING: TYPES OF ORDNANCE MAPS

1. METHODS OF SHOWING RELIEF

CONTOURS (Refer to Chapter III).—Contours are the most important means of showing relief, and form the basis of most other methods used for this purpose. Most maps of the Official Surveys of Britain, her colonies, and of the principal European countries use contours. Exceptions are very small-scale maps and very large-scale maps intended primarily for estate purposes or as town plans. British maps use the foot as the unit of the vertical interval, *i.e.* the interval between successive contours, but most foreign countries employ the metre. Great variety of interval is employed and frequently certain contours, say, every fifth or tenth contour, are thickened to facilitate reading. Examples are British, U.S.A., Swiss, and French maps for regions with considerable altitude. Most contoured maps show a goodly number of isolated spot heights, which are of great assistance in helping the visualisation of minor features.

Contours are usually numbered so that they read "up-hill"; see the figures printed upside down in the north-east part of the frontispiece map.

BENCH MARKS.—Marks consisting of a broad arrow surmounted by a horizontal line are placed (usually about two feet above the ground) on buildings, walls, etc., to mark positions whose heights above datum have been determined by levelling. Generally they are cut into the brick or stone, though some are on bronze plates let into the wall. The height of the middle of the horizontal line is printed on most large-scale plans. (See the arrow and "B.M. 67.2" on the corner of Hylands Farm on the 25-in. Plan facing p. 84.) Heights are constantly revised particularly in areas where subsidence is rife; the Ordnance Survey will supply up-to-date information for any area if exactitude is required.

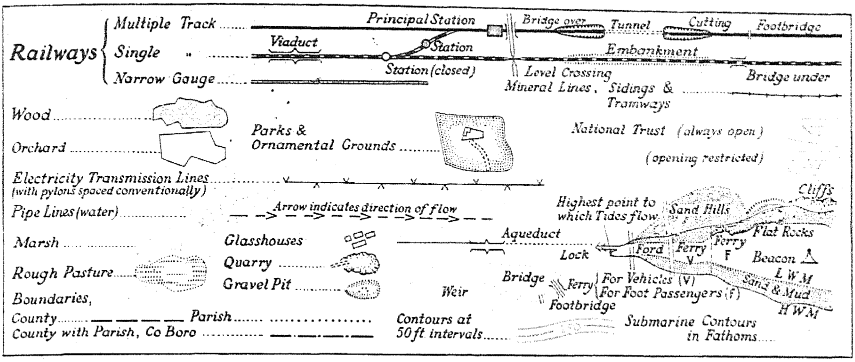
TRIGONOMETRICAL STATIONS.—These are sometimes shown with their height. Chapter IV describes triangulation, the method of dividing a country

into triangles for the purpose of survey. Trigonometrical stations are shown by a small triangle on 1-in. maps, and on 6-in. and 25-in. plans. Spot heights without this triangle are not trigonometrical stations.

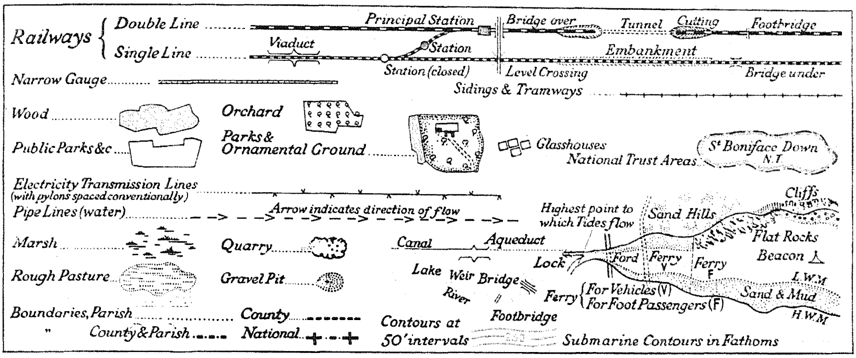
HILL-SHADING.—A light is imagined to be over the region and to cast shadow in some parts, to illuminate others. One method imagines that the light is vertical over the land, and that the steepest slopes are lit up the least. Thus the sides of hills and mountains are shaded dark, while relatively flat land, such as valley bottoms, plateaux, hill-tops, and mountain peaks, is of lighter tint. Another method imagines that the light shines from the north-west of the area, thus casting shadow over the eastern and southern slopes of higher land. Hill-shading does not show absolute heights. Relative heights are not very clearly indicated, nor are gradients, which are so well shown by contour lines. Usually it is not easy to determine from hill-shading what is uphill and what downhill. The same drawback is associated with hachures. Hill-shading does, however, give a general idea of the relief of a country, and is suitable for smaller-scale maps, as the 4 ml. to the inch, and the 10 ml. to the inch of the British Ordnance Survey.

HACHURES.—These are short lines which are supposed to indicate the direction water would take if flowing from high ground to low. For steep slopes the hachures are closely spaced, for gentle slopes they are wider apart and are thin, but flat ground is not shaded in any way. It is necessary in hachured maps to have plenty of spot heights in order to ascertain the approximate altitude. Hachuring does not clearly indicate absolute heights, and this limitation, as well as the drawback of closely-packed and not very legible hachures in mountainous country, has made the method lose favour with modern map makers. It was one of the earliest methods of showing relief, and was favoured by Napoleon Buonaparte. It was used on most standard maps during the nineteenth century, and some of these older standard maps are still in use, notably the 1 : 80,000 map of France.

Contours are sometimes supplemented by hachuring or by hill-shading, the auxiliary methods being useful to show minor features which would be lost if only contours were used, especially when the contour interval is fairly large. Such methods were used in early British 1-in. maps and again in some fifth edition $\frac{1}{2}$-in. and 1-in. maps.



Seventh Series 1 in. to 1 mile.



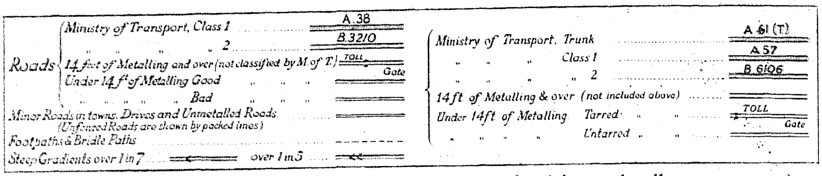
New Popular (Sixth) Edition 1 in. to 1 mile.

Heights in feet above Mean Sea Level	·275	*Lighthouse* / *Lightship*	
Triangulation Station	Δ	*Post Office*	P
Youth Hostel		*Telephone Kiosk* P.O.	T
Bus & Coach Stations		*Telephone Kiosk* A.A.	A
		Telephone Kiosk R.A.C.	R
Church or Chapel with Tower		*Antiquities*	
" " " *Spire*		*Prior to A.D. 43*	Tumulus
" " " *without either*	+	*Roman A.D. 43 to A.D. 420*	VILLA
Wireless Aerial Mast		*Later than A.D. 420*	Castle
Windpump		*Site of Antiquity*	+
Windmills (in use) ... (disused)		*Site of Battle*	

Seventh Series 1 in. to 1 mile.

Heights in feet above Mean Sea Level	·285	*Church or Chapel with Tower*	
Trigonometrical Point	Δ	" " " " *Spire*	
		" " " *without either*	+
Intersection, Latitude & Longitude at 5' intervals (not shown where it obliterates important detail)	+	*Site of Battle*	Hastings (A.D. 1066)
		Wireless Aerial Mast	
Youth Hostel	Y	*Windmill*	
Post Office with Telegraph and Telephone	P	*Windpump*	
Other Post Offices	*P*	*Lighthouse*	
Telephone Kiosk (G.P.O., A.A., R.A.C.)	T	*Lightship*	

Fig. 41A. SYMBOLS. New Popular (Sixth) Edition 1 in. to 1 mile.



New Popular 1 in. to 1 mile. Seventh Series 1 in. to 1 mile.

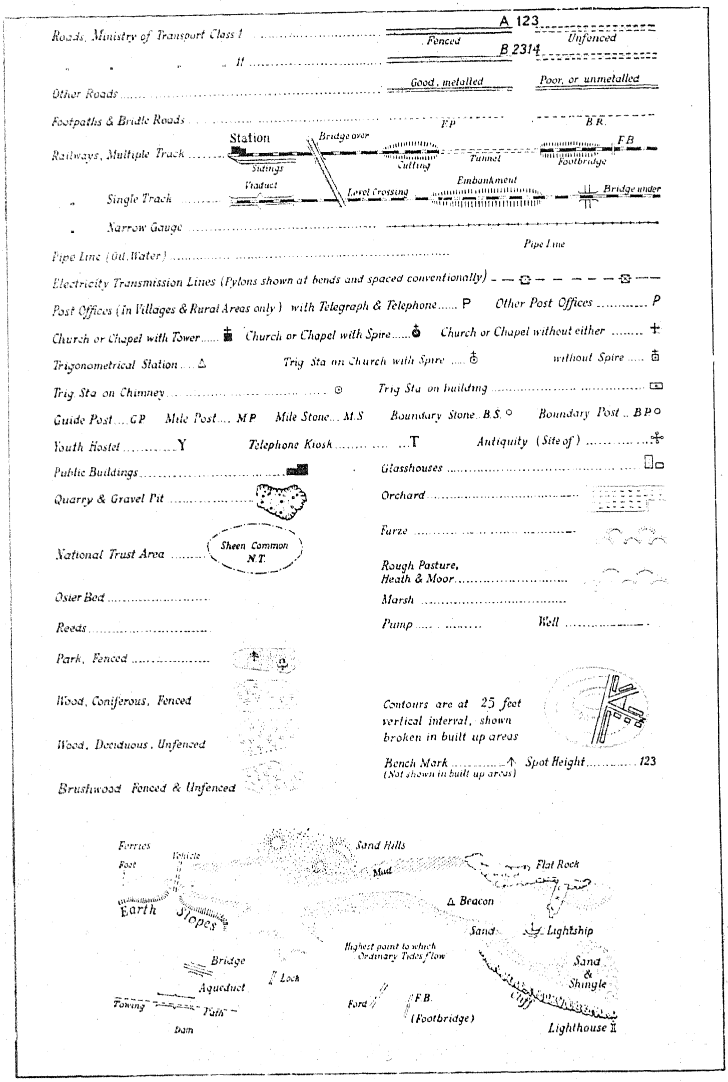


Fig. 41B. SYMBOLS. 1 : 25,000 (*ca* 2½ in. to 1 mile).

LAYER TINTS.—Either colours or different methods of black and white shading are used in combination with contours, especially in atlas maps. Examples of the method for larger-scale maps are the famous International map on the scale of 1 : 1,000,000, and certain layer-tinted Ordnance maps, especially the layered ¼-in. and ½-in. maps. Various shades of green for low, brown for higher, and pink for very high land are used in the colour method. A great advantage of the method is that distribution of high and low land can be readily grasped. Objections are that in very high country tints may be so dark as to make the insertion of legible detail impossible. When contours are very close, layer tints do not conduce to clarity. The layer method is very useful for showing on small-scale maps the absolute and relative heights of the principal physical features.

2. CONVENTIONAL SIGNS

To aid legibility in map reading, it is necessary to employ distinctive symbols for various features, and to make use of different types of lettering for different purposes. These symbols and methods of lettering are set out in what is known as the *Characteristic Sheet of the Conventional Signs and Writing*, used for the various types of Ordnance maps. They differ somewhat for each type. For example, more symbols for certain purposes are used for the 1-in. map than for the 6-in. plan, and symbols for the same feature are not always the same on both series.

In connection with conventional signs, use is made of colours and symbols. On many maps streams are blue, woods are green, and roads are red. Such colours at once give a clue to the features depicted. Methods for showing relief deal mainly with physical features, especially land forms. There are numerous symbols to indicate man-made features, such as roads, railways, canals, bridges, aqueducts, churches, windmills, water-pumps, beacons, lighthouses, houses, and other buildings.

Such conventional signs are shown on what is termed a characteristic sheet, and some are given on the margin of the official maps (see Figs. 41 to 43). They are best learnt by constant practice in interpretation and application. Popular and easily understood descriptions of the British Ordnance Survey maps are contained in official publications issued by the Ordnance Survey Department. These should be obtained, as well as Index Sheets of the maps on the scale which it is intended to use. From these

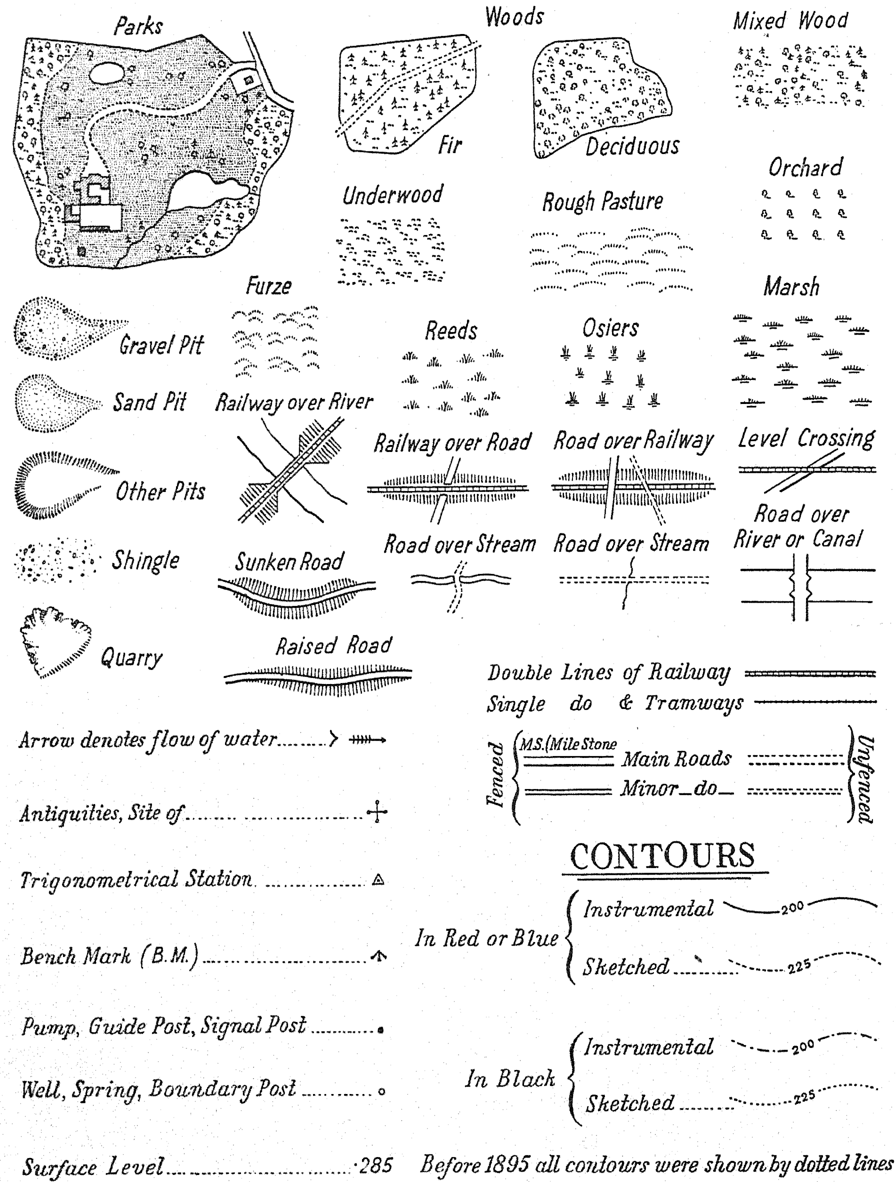


Fig. 42. Symbols Used on the 6-in. Plan of the Ordnance Survey.

BOUNDARIES

Counties		Parliamentary County Divisions	Parly. Div. Bdy.
County and Civil Ph.		Poor Law Unions (Obsolescent)	Union Bdy.
Ridings		Parliamentary Boroughs	Parly. Boro. Bdy.
County Boroughs (England)	Co. Boro. Bdy.	Divns. of Parly. Boroughs	Div. of Parly. Boro. Bdy
County Burghs (Scotland)	Co. Burgh. Bdy.	Catchment Areas	C.A.Bdy.

Municipal Boroughs	Munl. Boro. Bdy.
Urban Districts	U.D. Bdy.
Police Burghs (Scotland)	Burgh Bdy.
Rural Districts	R.D. Bdy.
Civil Parishes	

ALTITUDES (in Feet)

The Altitudes are above the mean level of the sea at Liverpool or Newlyn (as stated). The Contour altitudes are written thus ...200. Altitudes along roads and to Trigl. Stations obtained by Spirit Levelling, are written thus 300·, the dot showing the spot at which the altitude is taken.

Altitudes with the letters *B.M.* marked ↑ against them, refer to marks made on Buildings, Walls, Milestones, etc.

The Latitudes are given on the margin to every 30 seconds, and the Longitudes to every minute.

Fig. 42 *continued.*

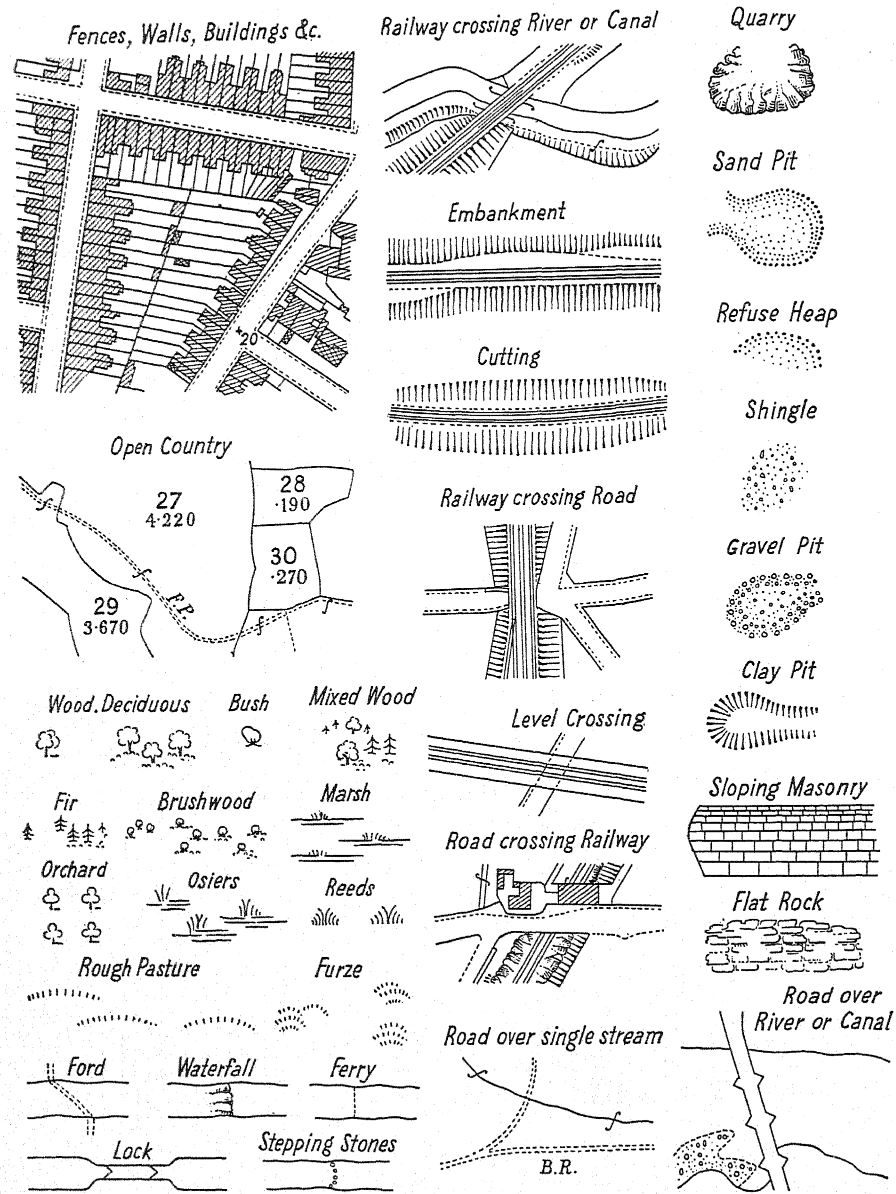


Fig. 43. Symbols Used on the $\frac{1}{2500}$ Plans of the Ordnance Survey.

Index Sheets it is possible to identify the map of any particular region and to gauge its extent.

Both the 1-in. and $2\frac{1}{2}$-in. maps are widely used for ordinary purposes, and are generally selected for examination questions dealing with map interpretation and analysis. Therefore it will be advisable to procure characteristic sheets for each of these and to study them carefully. Until you are familiar with the various symbols, always have the appropriate sheet by your side when studying the map, and from time to time refer to it for revision. Excerpts from the characteristic sheet are printed in the margin of Ordnance maps, but they do not show all symbols, nor do they emphasise the significance of various kinds of lettering.

3. ONE-INCH ORDNANCE MAPS

Probably the most familiar Ordnance map is that on a scale of 1 in. to the mile, or representative fraction 1 : 63,360. There are various styles and editions of this map. That of 1931 is termed the Fifth (Relief) Edition. The contours are for intervals of 50 ft, and by means of hill-shading and layered tints, the appearance of a model with three dimensions is secured. Sheets of the Fifth Edition were also produced without the hill-shading and layered tints. The New Popular (Sixth) Edition (published 1946-7) differs in a few symbols, but mainly in including the National Grid system for reference (see p. 255).

Previous to 1892 the Ordnance maps were printed in black, with the exception of brown hachures, but in 1892 a new edition was produced, in which streams and other water features were in blue, the roads in brown, contours in red, with brown hachures. This edition lasted until the issue of the Popular (Fourth) Edition.

The country is now covered by the new Seventh Series map, examples of which are studied in Chapter XIII. In this very fine map, which involves twelve or thirteen colour-printings, a very clear style of lettering has been employed, and grey is used instead of black for built-up areas, grid lines, and tree symbols. All lettering referring to water is now in blue, and there are a number of changes in conventional signs compared to the Sixth Edition. (A key plate will be found facing p. 76.) There is a revised road classification, new signs for railways, and changes in connection with National Trust areas, youth hostels, and telephone kiosks. Bus and coach stations are now shown.

On the current 1-in. maps, towns, villages, hamlets, isolated farmsteads, roads, footpaths, railways, stations, woods, parks, and country seats, rivers, canals, lakes, county and parish boundaries, are shown, with many features applicable to certain districts, such as cliffs along the coast as at Brighton and Flamborough, beacons along parts of the coast, windpumps for raising water in dry regions such as chalk country.

Some large sheet tourist edition maps on a scale of 1 in. to the mile are obtainable. Those for the English Lake District, the Peak District of Derbyshire, and the Trossachs of Scotland are specially recommended for study. They afford good practice in the study of relief features of considerable variety, and the general geographical aspect of these regions is varied. They combine colour layering with contours. The new 1-in. Tourist Series is based on the 1-in. Seventh Series material. This depicts relief by a combination of layer tints and hill-shading.

4. HALF-INCH AND QUARTER-INCH ORDNANCE MAPS

The smaller maps, namely the so-called $\frac{1}{4}$-in.[1] and $\frac{1}{2}$-in. maps, are on the lines of the 1-in. maps, but the relief is not shown in such clear detail, and other features are on a smaller scale. They are, however, useful maps, and should be studied along with the 1-in. maps. This will enable comparison to be made and will give exercise in the appreciation of the purpose of scales. Relief is indicated by means of contours and layer colouring; water features are shown in blue.

The large sheets of the revised Fourth Edition of the $\frac{1}{4}$-in. maps give a very graphic general picture of a considerable extent of country. Sheet 6, which is entitled "North Midlands and Lincolnshire", includes Leeds and Bradford in the north; Burnley, Manchester, and Stafford in the west; Leicester and Oakham in the south; King's Lynn, Grimsby, and Hull in the east; and thus affords excellent contrast between the higher land of the Pennine-Peak region and the lowlands of the Fens and coastal marshland. The black of the habitations stands out very clearly, especially in the larger towns, which, with the vividly-coloured roads, illustrate the meaning of nodality. Continuation of the roads, with their Ministry of Transport numbers, and indication of direction in the margin off the map, is a very

[1] The scale of this map is now 1 : 250,000 or "about four miles to the inch".

useful feature. A Fifth Series $\frac{1}{4}$-in. map has now replaced the Fourth Edition. Great Britain is covered by 17 sheets instead of the 12 of the Fourth Edition. The new sheet 11, however, covers approximately the same area as sheet 6 of the Fourth Series, described above.

The new $\frac{1}{2}$-in. Map Second Series will comprise 51 sheets each covering about 50 miles E.-W. and 60 miles N.-S. Hill features are portrayed by graded layer tints, and contours shown at 100-ft intervals. The National Grid is drawn at 10-km. intervals. The map is intended to be of special interest to motorists and cyclists, for it shows much detail of the countryside and includes antiquities, youth hostels, golf-courses, and telephone kiosks outside built-up areas.

5. MEDIUM AND LARGE-SCALE SHEETS

The $2\frac{1}{2}$*-in. map*, as it is known, uses a scale of 1 : 25,000. It is ideal for regional survey and for fairly detailed study of the human features of the countryside. Contours are brown and are broken in built-up areas. They are shown for vertical intervals of 25 ft, every other one being inserted by interpolation only, between the surveyed 50-ft contours of the 6-in. map. Trigonometrical stations are shown on churches, chimneys, or other buildings. Parish boundaries are given and they will not be confused with footpaths, as dots wider apart are used. Ministry of Transport Class A roads have continuous brown lines, Class B roads disconnected brown lines, and in both cases distinction is made between fenced and unfenced roads. There are also other roads, fenced and unfenced, not accepted by the Ministry of Transport; they are uncoloured. Multiple track and single track and narrow gauge railways are indicated by the usual symbols. Electricity transmission lines and pipe-lines (oil and water) are indicated, and on the first-named pylons are shown. Streams, lakes, and ponds are depicted in a legible blue; pumps, wells, springs, and blow wells are shown. There are symbols for furze, marsh, reeds, osier beds, rough pasture, heath and moor, and watercress beds are named. Distinction is drawn between fenced and unfenced, deciduous and coniferous, woods, and orchards are shown. In built-up areas the general outlines of buildings and streets are clear. The various topographical symbols, such as bridges, embankments, cuttings, are very clear.

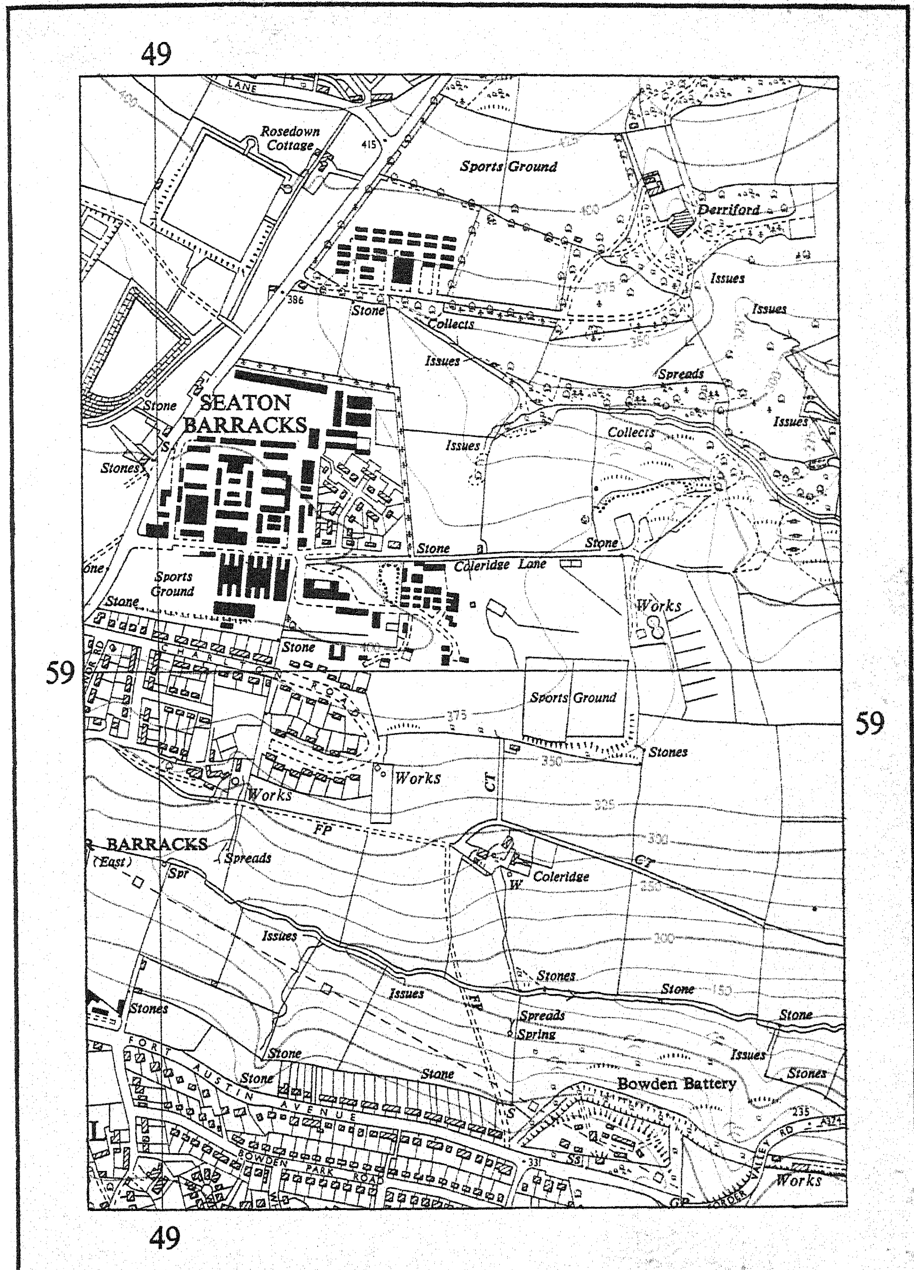
Of medium-scale sheets, the 6-*in. series* is very useful and well known.[1] Contours up to 1,000 ft are at 50-ft intervals, but above 1,000 ft the 250-ft interval is used. The contours are shown in red. Contours at 50- and 100-ft vertical intervals were determined by actual survey with instruments, but in some sheets, including that from which the extract facing this page has been taken, sketched contours, or form lines, for 25-ft intervals are inserted. These maps are not coloured, and because of the black printing, features sometimes are not easy to follow without considerable practice.

Plans on a scale of 25 *in. to the mile* are large enough to show sufficient detail to be useful to the landowner and farmer. Field boundaries are clearly shown, and some sheets indicate the area of enclosures. The map is published for the cultivated districts of Great Britain, and the fact that it is not available for uncultivated districts explains its function. The 25-in. plan shows hedges and fences, but the real boundary of property is often some little distance beyond the hedge. Hence this is not literally a cadastral map in the same sense as a French **cadastre**, although it is frequently known as a cadastral map.

Sheets on a scale such as 60 *in. to the mile* or a scale of 1 : 500 (= 126·7 in. to the mile) are also plans, and were issued for towns only. Both these series are now obsolete as far as the Ordnance Survey is concerned, and are being replaced by a new 50-in. to the mile map (1 : 1,250), also for towns only. The scale is large enough for buildings to be named and numbered and for letter-boxes to be shown, but features connected with public services, such as lamp-posts and hydrants, shown on the earlier maps, are omitted. Survey and mapping of services is now carried out privately by the towns concerned.

Six-inch and 25-in. plans are given (facing this page) and it will be seen that, unlike the 1-in. map, all features are to scale and none need be exaggerated. A noticeable feature is the field boundary. This is particularly well shown on the 25-in. specimen. The fields are numbered for reference, and the acreage is shown. The continuous line of dots in the south-east corner of the map represents the line of a hedge. The double parallel lines denote a road or footpath (marked F.P.). The buildings are clearly shown to scale, and the symbols for trees are sufficiently large to enable clear distinction to be made between conifers and deciduous trees. This is a neat little map of a complete economic unit, a farmstead.

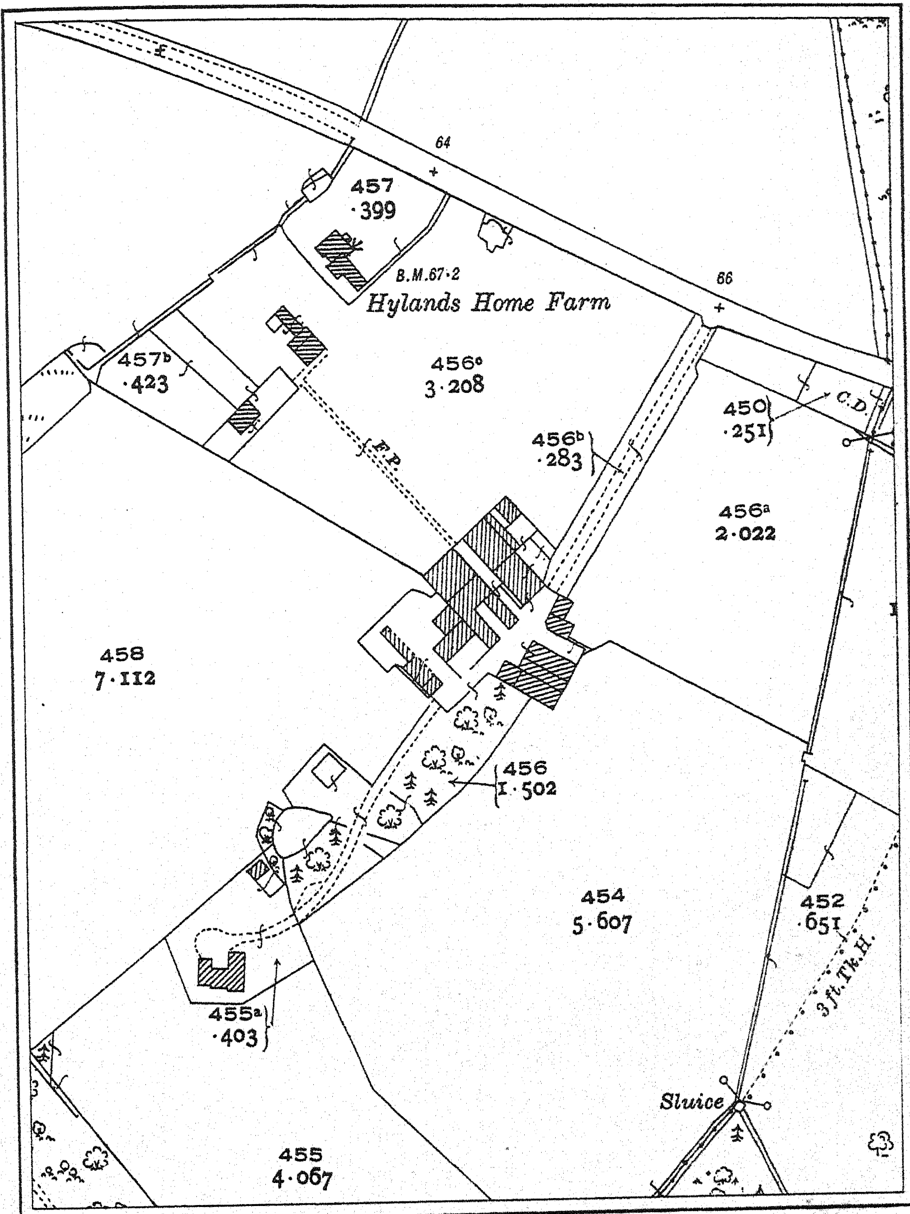
[1] The resurvey of this series on National Grid Sheet lines is nearly complete.



W.&A.K. Johnston & G.W. Bacon Ltd., Edinburgh & London.

TWENTY-FIVE INCHES TO ONE MILE.

A small portion of Sussex (East) LXVIII. 4.



W. & A. K. Johnston & G. W. Bacon Ltd. Edinburgh & London.

On the 6-in. plan, fields are shown, but in less detail than in the 25-in. plan, which serves admirably for estate plans. The 6-in. plan shows contours in red (these are not included on the larger-scale map). Slopes can be traced, and a section might be drawn from Bowden Battery northwards to the Sports Ground (at the top of the plan). Note the copious information about the streams, "Collects", "Issues", and "Spreads"; and also the way official and public buildings are shown in black.

6. THE LAND UTILISATION MAP

An interesting adaptation has been made of the 1-in. Ordnance Survey map. Some sheets have been issued to show the cartographical results of a Land Utilisation Survey directed by Dr Dudley Stamp; the object of the survey, in the words of its director, being "to make a complete record over the whole of Britain of the uses to which the land is put at the present time". This took place between 1931 and 1939; each sheet shows its own date of survey.

The basis of the special **Land Utilisation map** is the 1-in. map (Popular Edition) on which additional information is printed in six colours. A distinctive letter symbol is used with each colour. Dark green (F) is used for forest and woodland; light green (M) for permanent grass and meadow; brown (A) for arable land; yellow (H) for heath, moorland, commons, and rough pasture; purple (G) for allotments, gardens, and orchards; red (W) for land of no agricultural value. The method is easy to follow, and the ordinary details of the map can be read quite easily, and though the added colour tends to obscure relief features, these can be read. A map of this type is shown facing p. 148. You should aim to study contrasting maps, such as the One-Inch Sheet No. 114, Windsor, covering the region south-west of London, and Sheet No. 142, Isle of Wight, including part of the New Forest and Portsmouth, two very dissimilar areas, one typically urban and suburban, the other largely rural.

The Land Utilisation map, as well as being of interest to contemporary geographers, should not be without eventual historical value, in the way that the Agricultural Surveys of Arthur Young give a picture of the agriculture of certain British counties at the end of the eighteenth century. His surveys were more generalised and were descriptions of farming methods seen during journeys rather than detailed scientific surveys of all the land.

Preliminary work for the production of a new Land Utilisation map was started in 1961. Such preparation must of course take several years in order that recordings of successive forms of agricultural land use in one area can be recorded.

Other interesting maps of the Ordnance Survey are Aviation maps: the ¼-in. Civil Air edition covering England and Wales (12 sheets) with special information relating to flying, and a map covering Great Britain (3 sheets) on a scale of 10 ml. to the inch, with flying information symbols in blue, showed conditions previous to 1939. There is also a 10 ml. to the inch layered map of Great Britain (3 sheets) intended for motorists and others who require maps covering a large part of the country.

The Ordnance Survey have issued maps on a scale of 1/M, notably a population map of Great Britain based on the 1931 census, historical maps, such as of Roman Britain and Britain in the Dark Ages, a physical map of Great Britain, and one in International style. There is also a Geological Survey 1/M map showing British coalfields.

CHAPTER IX

GEOLOGICAL MAPS

1. WHAT THEY PORTRAY

Geological maps are very useful to the geographer in helping him to understand the character of physical features and soils, the distribution of minerals, and the problem of water supply. He does not need to study them with that intensity and attention to technical detail necessary in the case of the trained geologist or the mining engineer, but he must grasp certain broad principles.

Geological maps contain information with respect to the nature, age, and relation of rocks which constitute the upper part of the earth's crust. They also indicate the way in which the various beds of rock are inclined. It is possible to draw sections illustrating the relative positions the rocks would occupy in a solid model. Such sections are a great help when we examine the physical geography of a region of contrasted relief where hills and valleys alternate. Both Ordnance Survey and geological maps can be read without drawing sections, but practice in drawing such sections leads to facility in grasping the essential details and in interpreting the map.

The geological map, in addition to details concerning the rocks, contains much of the information given by the ordinary topographical map, such as streams, routes, and settlements. One-inch Geological Survey maps show contour lines, bench marks, and trigonometrical stations, but it is an advantage to use an Ordnance Survey map for the relief, because the data can be more readily seen.

For England and Wales there are two kinds of geological maps for certain districts, namely the **solid** and **drift** editions. The solid map shows everything except glacial deposits, and includes peat, alluvium, river terraces, older river gravel, blown sand. The drift edition shows all recent deposits as well as (1) glacial drift; (2) older formations where these are not covered by any of the newer deposits. Drift maps are published for those regions, especially eastern and northern England, which were formerly overlaid

by the ice-sheet of the Ice Age. When possible, both the drift and solid geological map of the region should be used. The former is invaluable in explaining the soil variations; the latter is useful for study of land forms and water supply.

The geological map, by means of different colours or stippling, shows the age and extent of the rocks which constitute the earth's surface. Symbols are used to denote the position and extent of mineral veins and fractures (known as "faults") which have affected the general relationship of rocks in some districts. These can be seen in the keys printed on the margin of all geological maps. The following symbols may be specially noted:

↘ 10° Denotes a dip (in quarries, railway cuttings, etc.) of 10° to SE. at the point where the arrow appears on the map.

8° ↖ A dip of 8° to NW.

↖ ↘ Indicates direction, but not amount of dip. (Usually dip is small in these cases.)

+ Indicates horizontal strata.

Indicates vertical strata: longer line gives strike direction.

Undulating beds.

Anticlinal axis (top of an arch of upfold).

Synclinal axis (*i.e.* bottom of a downfold).

2. THE CLASSIFICATION OF ROCKS ACCORDING TO ORIGIN

Rocks of the earth's crust, according to their origin, are divided into three main classes: (1) igneous, (2) sedimentary, (3) metamorphic.

IGNEOUS ROCKS.—These are due to the cooling and solidifying of molten matter. They comprise lava ejected from volcanoes and from fissures (or cracks in the earth's surface), as well as molten matter which has crystallised below the surface and was exposed when erosion removed overlying rock. Granite and basalt are well-known igneous rocks.

SEDIMENTARY ROCKS.—Sedimentary rocks have accumulated as sediment at the bottom of seas, lakes, and river mouths, and were formed in relatively horizontal layers, though since formation they have often been changed by certain forces from their original horizontal position. Some sedimentary rocks, such as sand, are due to accumulation of fine-grained material, largely quartz, which has been worn down by wind from debris eroded from other rocks.

Well-known sedimentary rocks are sandstone, grits, clay, shale, limestone. **Sandstone** is formed when sand is made coherent by some cementing material

such as calcium carbonate or oxide of iron. **Grits** comprise sandstones in which the original grains of sand are mainly angular. **Clay** is a fine-grained deposit, largely a hydrated silicate of aluminium, which is plastic because of the moisture which it contains. **Shale** is a clay or silt which has been hardened and laminated, that is, arranged in a series of layers. **Limestone** consists mainly of calcium carbonate derived from shells and skeletons of shell-fish, corals, and other creatures in the sea in which it was formed. Limestone is either hard or soft, in which latter form it is known as **chalk.** Not all limestones or other sedimentaries have originated "first-hand", some are due to wearing away of former sedimentary, igneous, and metamorphic rocks, and to redeposition of the debris.

METAMORPHIC ROCKS.—These have been formed by some great alteration of some other rock, which, before change, may have been of igneous or sedimentary origin. The alteration has been due to great pressure, heat, or a combination of heat and pressure. Metamorphic rocks are generally very highly crystalline, and those due to pressure usually much crumpled and contorted. Gneiss, crystalline schist, marble, and slate, are metamorphic rocks.

3. THE CLASSIFICATION OF ROCKS ACCORDING TO AGE

Rocks are also classified according to their age, and a grasp of this method is necessary to understand geological maps. The rocks are divided into groups or formations according to their geological age. Some of the principal formations noted on British maps are here given, arranged in the order normally followed in keys to the geological map, namely, the newest rock at the top and the oldest at the bottom. The lowest formation takes number 1 and letter *a*, and other numbers work upwards with letters according to alphabetical order.

26 Recent and Pleistocene, comprising alluvial drift, such as silt and gravel; peat; glacial drift, such as boulder clay, sand and gravel.
25 Pliocene: a group of shelly sands and gravels, with occasional seams of clay.
24 Oligocene: shelly clays, sands, and limestones.
23 Upper Eocene: sands and clays.
22 Lower Eocene: clay (London and other clays), and sands.
21 Chalk.
20 Upper Greensand and Gault Clay.

19 Lower Greensand.
18 Wealden: Weald Clay, Hastings Beds (sands, sandstones, and clays).
(Nos. 18-21 are known as Cretaceous rocks.)
17 Purbeck Beds: clays and limestones.
16 Upper Oolite: Portland Beds (limestones and sands), Kimeridge Clay.
15 Middle Oolite: Corallian (limestones and sands), Oxford Clay, Kellaways Beds.
14 Lower Oolite: Inferior Oolite (sands and limestone), Great Oolite (clays and limestone), Cornbrash (limestone).
13 Lias: upper (shales), middle (ironstone, limestone, sands, and clays), lower (clays and limestone).
(Nos. 13-17 are known as Jurassic rocks.)
12 Upper Trias (Rhaetic, Keuper): marls, shales, sandstones, and rock salt.
11 Lower Trias (Bunter): sandstones, sands, and pebble-beds.
10 Permian: (*a*) magnesian limestone; (*b*) sandstone, conglomerate, marl.
9 Coal Measures: shales, sandstones, clays, fire-clays, iron-ores.
8 Millstone Grit: grits, sandstones, shales.
7 Yoredale Series: shales and limestone.
6 Carboniferous Limestone.
5 Devonian: shales, grits, and Old Red Sandstone.
4 Silurian: shales and grits.
3 Ordovician: limestone, slates, and grits.
2 Cambrian: slates and grits.
1 Pre-Cambrian or Archaean: schists, slates, grits, Torridonian Sandstones. Such rocks are largely metamorphic.

Numbers 2-26 above are classed as sedimentary rocks, and contain fossils. They are broadly arranged in groups according to age, namely **Primary,** the oldest, numbers 2-9; **Secondary,** numbers 10-21; **Tertiary,** numbers 22-25; **Quaternary,** number 26.

Some pre-Cambrian rocks, *e.g.* Torridonian Sandstone, are also sedimentary in origin.

Igneous rocks are of all ages, some of the best known being granite, basalt, and serpentine rocks.

On geological maps rocks are distinguished by various colours, and sometimes by the addition of a distinguishing letter and number, for example, *Pleistocene* rocks are shown by buff and the letter *l*; *Cretaceous* by various shades of green and the letter *h*: Wealden Beds by h^1, Lower Greensand by h^2, Gault by h^3, etc.; *Jurassic* by browns and yellows and the letter *g*; *Triassic* by pinks and the letter *f*; *Cambrian* by pale grey and the letter *a*.

Igneous rocks are always put at the bottom of an index list, whatever their age. Basalt is shown by the letter *B*, granite by *G*.

There are special colours, with symbols, to indicate peat, alluvium, river terraces (often gravel), boulder clay, glacial sands, and gravels which are used on many geological maps. It must be remembered, however, that while a geologist is primarily concerned with the age of a rock, and his maps are coloured accordingly, the geographer is more interested in its associated characteristics. It is often difficult to tell, for example, in the Wealden series (number 18), whether a bed is of porous sandstone or impervious clay from examining the geological map. In such cases, the memoirs published to accompany each map should be consulted.

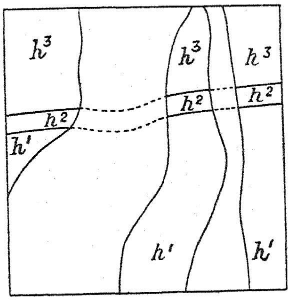


Fig. 44.

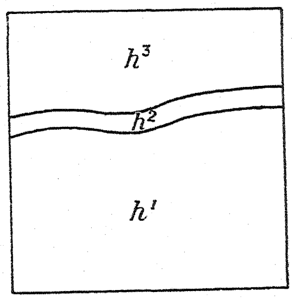


Fig. 45.

4. THE INTERPRETATION OF GEOLOGICAL MAPS

In interpreting a geological map, the first thing to do is to examine the map generally in order to see what formations are depicted on it. Then look for drift, which may occur in fairly continuous strips and patches, or in very small patches. It is well to realise that all drift is but a thin layer resting on the solid beds, and as a rule detailed consideration of drift should be left until the solid rock has been examined. At first it is well to picture the map as though the drift were not there. Sometimes the junctions of the solid rocks below the drift are shown by dotted lines, as in Fig. 44, and Fig. 45 shows how the solid beds should be pictured apart from the drift.

Beds of sedimentary rocks were laid down as relatively horizontal sheets (or **strata** as they are sometimes termed) of fairly uniform thickness. Many strata have later been tilted and folded, though the tilt or fold was often very

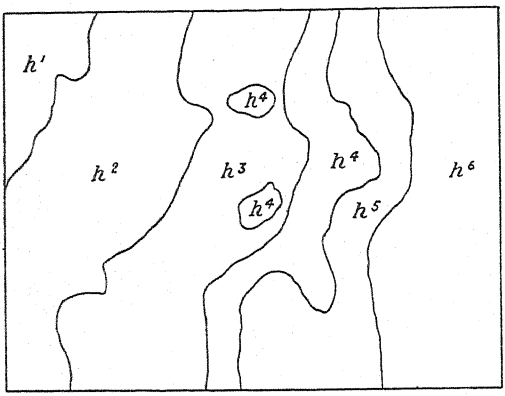


Fig. 46.

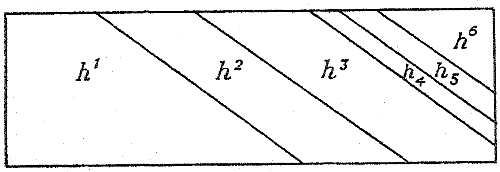


Fig. 47. SECTION ACROSS THE NORTH BOUNDARY OF FIG. 46, ASSUMING THE GROUND SURFACE TO BE LEVEL.

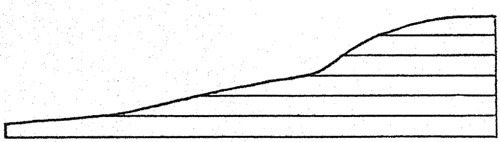


Fig. 48. SECTION ACROSS THE NORTH BOUNDARY OF FIG. 46, ASSUMING THE BEDS TO BE OF UNIFORM THICKNESS.

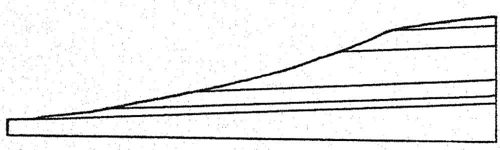


Fig. 49. SECTION ACROSS THE NORTH BOUNDARY OF FIG. 46, ASSUMING THE BEDS TO DIP TOWARDS THE WEST.

slight. Despite such folding or tilting the strata lie one on the other very like the parts in the volume of a periodical. Thus, if any particular bed **outcrops** (or appears at the surface) it is easy to reach an older bed below it.

After general examination of the map and picturing it apart from the drift, you should ascertain where the newest or youngest beds lie. In Fig. 46 it is evident that there is considerable outcrop of h^6 beds towards the east. Unless there is distinctly high land in the east, a fact determinable from the relief map, it is clear that the series of deposits h^1 to h^6 must have a "**dip**" (or downward trend) towards the east (Fig. 47). The beds h^1, h^2, h^3 must drop some considerable depth below the surface to allow room for the other members of the series. This method is reliable in picturing the dip of beds in relatively flat or undulating country. The inclination or dip of the bed must not be confused with *slope* of the ground.

If the ground rose towards the east, the strata

might lie relatively horizontally (Fig. 48) or might dip slightly towards the west (Fig. 49). When lines indicating geological junctions run roughly parallel to the contours (Fig. 50) the strata are generally horizontal. When the beds are horizontal, outcrops of the newer rocks are found wherever there are hills, and not merely in one particular part of the map as might be the case when there is a tilt. The patches of newest rock

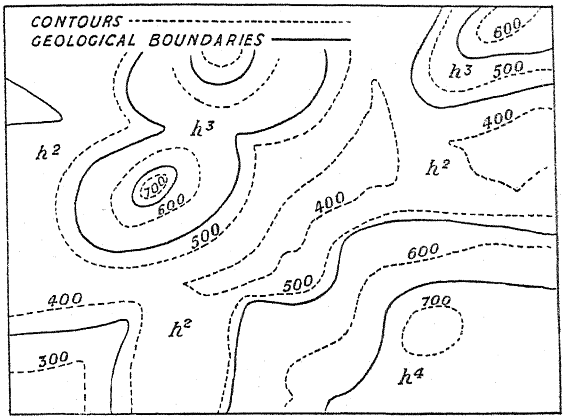


Fig. 50. (Fig. 51 is section from SE. to NW. of Fig. 50. at a reduced scale.)

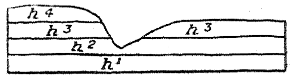


Fig. 51.

forming the hill-tops are termed **outliers**. In such a case it is easy to visualise the profile of the country, to see it as it were, like a block model which has been cut downwards to expose a "section" showing the various strata (Fig. 51). Outliers could occur in other ways, not necessarily on hill tops.

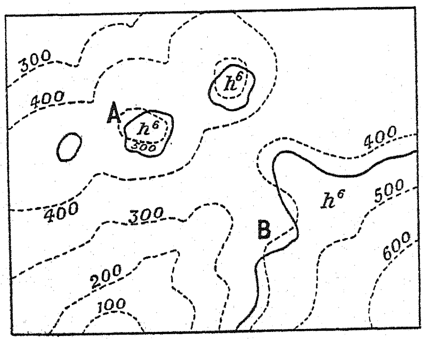


Fig. 52.

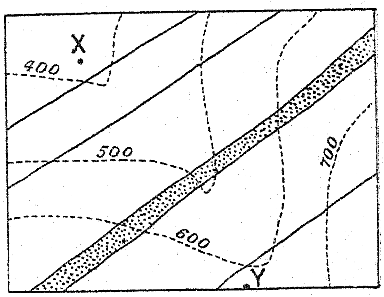


Fig. 53.

Beds, however, are rarely quite horizontal. Wherever there is a slight dip the geological junction lines cut across the contours. In Fig. 52 at

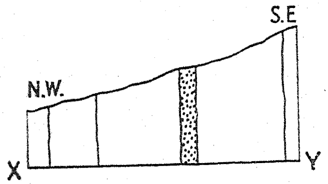


Fig 54.
Section across Fig. 53 from X to Y.

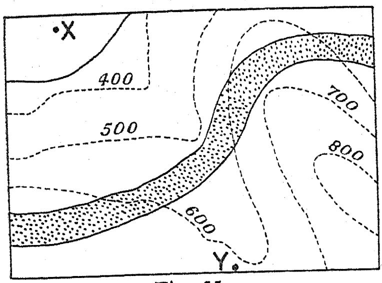


Fig. 55.

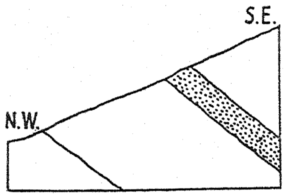


Fig. 56.
Section across Fig. 55 from X to Y.

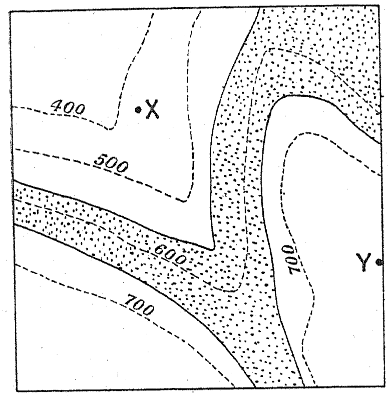


Fig. 57.

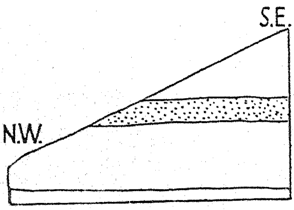


Fig. 58.
Section across Fig. 57 from X to Y.

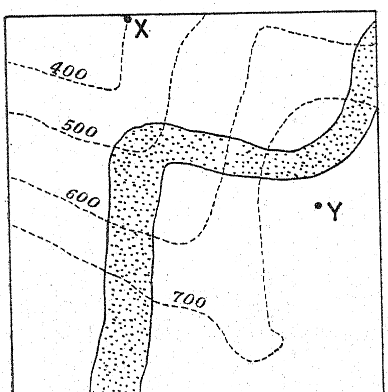


Fig. 59.

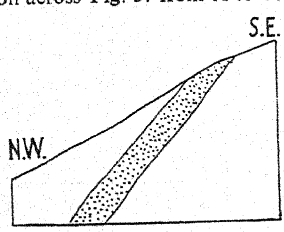


Fig. 60.
Section across Fig. 59 from X to Y.

A the junction is 500 ft above sea level; at *B* it is only 400. Then there is apparently a dip of 100 ft in a south-easterly direction along the line *AB*.

If the junctions are independent of the contours and the outcrops are narrow (Fig. 53), the beds are nearly or quite vertical (Fig. 54). This does not often occur. Beds dipping gently are more usual. Diagrams 54 to 60 illustrate dip.

Dip is expressed in degrees from the horizontal. Where it can be observed in quarries, cuttings, or other exposures, it is shown on the map by dip arrows. The dip is denoted where the *point* of the arrow is on the map. Often a dip arrow without number is given: in such cases direction but not amount is indicated.

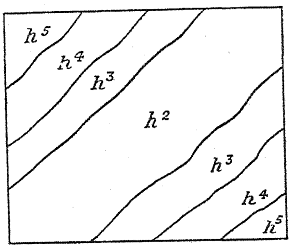


Fig. 61.

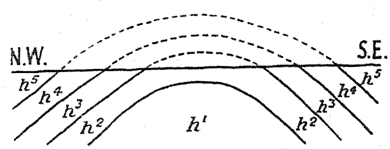


Fig. 62.
Section across Fig. 61.

Reference is here made to the true or maximum dip, and not to what is known as apparent dip. **True dip** is in a direction at right angles to the **strike**; dip in any other direction is less and is termed apparent dip. The **strike** of a bed is its intersection with a level plane.

Note that Figs. 53, 55, 57, 59 are maps, and Figs. 54, 56, 58, 60 approximate geological sections, Fig. 54 being made from Fig. 53, etc.

Where strata have been folded in the form of an **upfold** or arch, sometimes called an **anticline,** a strip of old strata is bounded on both sides by newer formations (Figs. 61, 62). Where folding has been in the form of a **downfold** or **syncline,** outcrops of older rocks are on both sides of a strip of newer rocks (Figs. 63, 64). Fig. 64 might be the section of a "basin" as well as of a downfold. The axis of either an upfold or downfold may be horizontal, though it may **pitch** or slope one or two ways.

The above diagrams are generalised sections drawn approximately, but sections should be drawn carefully from the maps with attention to available data.

In the diagram (Fig. 65) θ represents the angle of dip, x the width of outcrop, y the thickness of the bed, and z its depth. If the width of outcrop

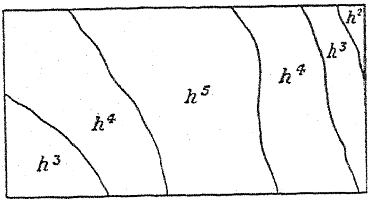


Fig. 63.

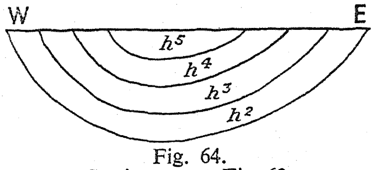


Fig. 64.
Section across Fig. 63.

(measurable from the map) and the angle of dip are known, the other values may be calculated thus:

$$y = x \sin \theta; \quad z = x \tan \theta.$$

Sin θ and tan θ can be found from a table of natural sines and natural tangents. And x sin θ means x multiplied by value of the sine of the angle θ.

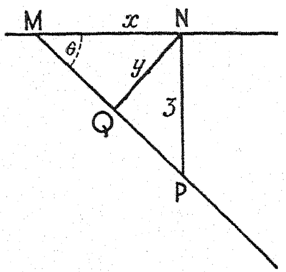


Fig. 65.

The thickness or depth of a bed can be obtained graphically. Thus (Fig. 65) draw angle *NMP* (*i.e.* θ) equal to the known angle of dip and mark off from *M* along *MN* the width of outcrop *MN* ($= x$). To obtain the vertical depth of the bed, draw from *N* a line *NP* at right angles to *MN*, cutting *MP* at *P*. This line *NP* ($= z$) is the required vertical depth. The true thickness is given by dropping from *N* a line *NQ* ($= y$) perpendicular to *MP*. This line *NQ* is the true thickness.

Dip, width, and thickness being known, we use such data in an ordinary topographical section drawn to scale from a contoured map. Note the section (Fig. 67) drawn from the contoured map (Fig. 66), the geological data being duly filled in from the geological map (Fig. 68).

A solid geological map shows the rocks *in situ*, that is, in their own positions where formed. A solid geological map of Lincolnshire will show

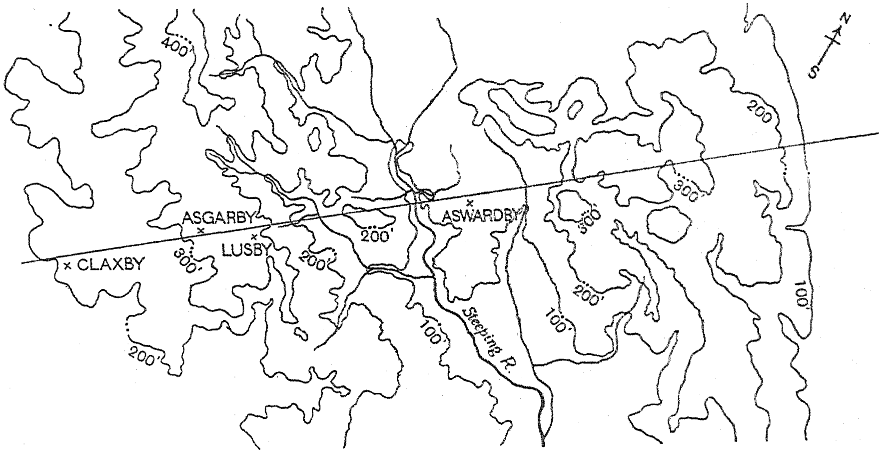


Fig. 66. Contoured Map of Part of Lincolnshire Wolds.
Showing direction of Geological section given as Fig. 67. Scale of Figs. 66, 68, and horizontal scale of Fig. 67 are identical.

the chalk of the Wolds, the limestone of the Lincoln Heights, the clay of the vale west of the Wolds. These rocks in many places are mantled with boulder clay, glacial sand, and gravel associated with the ice-sheet which once covered this country. These glacial deposits, as well as the alluvial deposits due to streams, are shown on the drift map. The best way to combine a study of contours and geological data is to make tracings of (1) the contours and (2) the streams of the relief map, (3) the solid geological map, (4) the drift geological map. These can be placed one on another. The drift map explains soils, boulder clay giving heavy soil difficult to work,

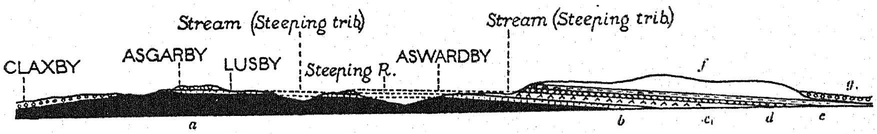


Fig. 67. Geological Section Across Part of Lincolnshire Wolds.
See Figs. 66 and 68. Vertical Scale exaggerated 6½ times. This section is adapted from the relevant Geological Survey Memoir by permission of the Director of the Geological Survey.
a = Kimeridge Clay; b = Spilsby Sandstone; c = Tealby Clay; d = Tealby Sandstone; e = Carstone; f = Chalk; g = Glacial beds (mainly boulder clay).

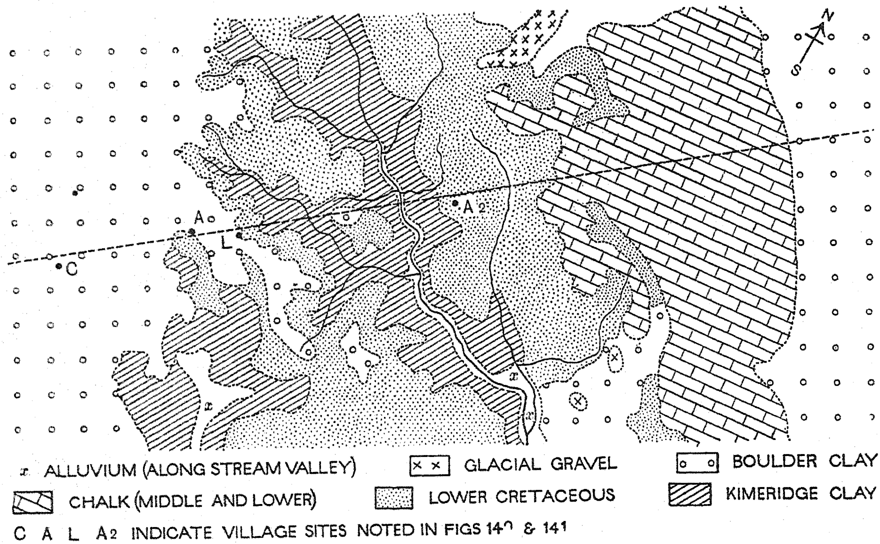


Fig. 68. Simplified Geological Map.
Based, by permission of the Director of the Geological Survey, on the one-inch geological map (drift edition).

and sand giving poor light soil; and it also accounts for the character of the clay in the Lincolnshire and Norfolk marshes, and the character of the boulder clay cliffs of Holderness or the "island" sites of gravel in the Fens where towns were originally built. There are no glacial deposits in Britain south of the Thames, and thus drift maps are not necessary here.

Figs. 66, 67, 68, show the relationship between the geology, relief, and village settlement in part of the Lincolnshire Wolds.

PART II—MAP READING

CHAPTER X

SETTING A MAP

1. THE MENTAL PICTURE

Ability to set a map and to identify your position are essential aspects of outdoor map reading, but some things connected with map reading can be done indoors, for instance, mastering conventional signs, and methods of showing relief. Such practice is best developed out-of-doors, but the alphabet of outdoor map reading can be learnt indoors.

To read a map requires knowledge of the methods of indicating relief, of the conventional symbols, of scales, of bearings, of the use and significance of the compass. Such things are, as it were, the alphabet and grammar of map reading, but taken singly and without proper combination and correlation, they no more constitute map reading than the Greek alphabet and grammatical rules constitute a knowledge of Greek literature. They are a means to an end, and must be used to create a mental picture of the country with which they deal. They must help us to visualise it as if we saw it from a high mountain or from an aeroplane. "We must learn to see solid."

The scale of a map is one of the first things which should be considered. Try to recall on the same scale some other map of country with which you are familiar. Note on the new map a small area corresponding in size to ground known to you. This will give a standard of comparison as regards extent, and you will probably be able to estimate how long you would take in walking, cycling, or motoring from one point to another. Such ability to think in terms of distance helps to give an air of reality to your mental picture.

Maps have been termed "the geographer's shorthand", and a geographer should be able to transcribe and to interpret the whole of the notes comprised in such shorthand. Given an Ordnance map, he must readily be able to

suggest suitable physical divisions, to trace the relation between physical features and the development of human settlement, and in a sense, build up a synthetic geographical description of the area.

2. SETTING A MAP

A very important part of map reading is the ability to locate one's exact position on the map. Part of this operation is **setting the map** so that, when held or laid on the ground, its north part does lie to the north. Here we must re-consider the meaning of bearing and note the three north points, true, magnetic, and grid, which are shown on the Ordnance maps.

The **bearing** of an object is its direction from the observer and is the angle at the observer between the meridian (the north-south line) through the observer and the line joining the observer to the object. Bearings may be given in two ways, (*a*) the **quadrantal** method, *e.g.* N. 40° E. or S. 35° W. (the figures never exceed 89°); or (*b*) the **whole circle** method in which bearings are measured clockwise from the north point, 0° to 359°; since this is the only point of reference it is unnecessary to add the letter N. when using this method; N. 40° E. becomes 040° and S. 35° W. becomes 215°.

A **true bearing** is one referred to the true meridian, the line, through the observer, joining the true north and south poles. A **magnetic bearing** is referred to the magnetic meridian, *i.e.* the line in which the compass needle lies, one (not necessarily straight) joining the north and south magnetic poles. Quadrantal or whole circle phraseology may be used for either type.

The magnetic poles (near Hudson's Bay and South Victoria Land in Antarctica) do not coincide with the true poles so, in most parts of the world there is an angle between the true and the magnetic meridians which is called **magnetic variation** (by sailors) or **declination of the compass** (by landsmen). This differs from place to place and also, because of a constant movement of the magnetic poles, changes from year to year.

Fig. 69 shows how information concerning variation is given on the 1-in. Ordnance maps; $\propto$ (which has been added to the figure) is the variation, in this case, for 1955, and it is decreasing by about $7\frac{1}{2}$ minutes of arc a year. It is important to note that the $10\frac{1}{2}°$ mentioned is not the variation but is the angle between the magnetic and the **grid** meridians. Grid meridians are the north-south lines of the National grid, printed on all Ordnance maps; they approximate to but do not coincide with true meridians except on the

line 400,000 E. (which runs down the centre of England close to Birmingham). See p. 255.

Magnetic observations are made over the land and oceans of the world and enable lines of equal variation to be drawn on charts (these are of great importance for the navigator); by repeating the observations at intervals the annual change is found. Observations are made daily at the Magnetic Observatory at Abinger in Surrey.

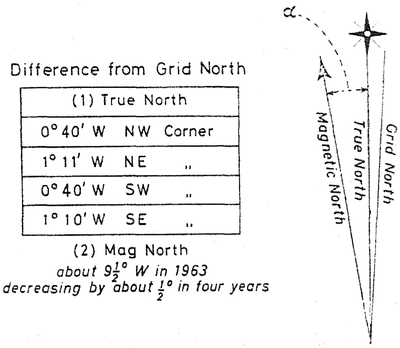


Fig. 69. NORTH POINTS AS SHOWN ON ORDNANCE MAPS.

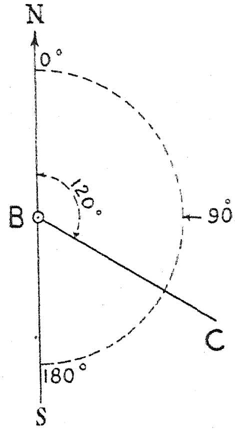


Fig. 70. TO OBTAIN A GRID BEARING FROM A MAP.

To find bearing of C from B, draw a grid meridian through B. Join B to C. With protractor (dotted line) read angle NBC, 120°, the forward bearing from B to C.

Magnetic bearings are observed with the compass in the field (note the precautions given on p. 59) but on the map, grid bearings are more convenient, and may be obtained as shown in Fig. 70. To plot a magnetic bearing on the map, first convert it into a grid bearing and then plot as shown in Fig. 34. To convert a whole circle magnetic bearing to a grid bearing subtract the westerly variation, *e.g.* using Fig. 69, a magnetic bearing of 215° becomes (in 1955) 215 — 10½ equals 204½°. (The average variation in Britain is about 10°, this may be used without much error for the conversion if the exact figure is not known.) Bearings from the observer to an object

are known as **forward or on bearings;** those from the object to the observer are **reverse or back bearings.** They should differ by 180°; with whole circle bearings one is converted into the other by adding, or subtracting, 180°; with quadrantal bearings the letters are reversed so the back bearing of a NE on bearing is SW, and of a NW on bearing is SE (see Fig. 72).

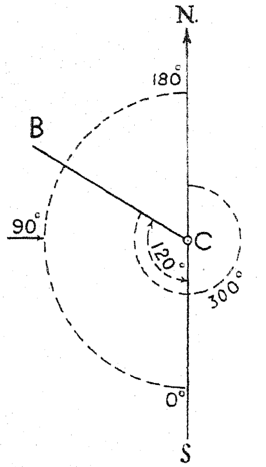


Fig. 71. TO OBTAIN TRUE BEARING FROM A MAP.

To find the bearing of the bridge (B) from the church (C) draw the true north-south line through C and join the position of the church (C) to that of the bridge (B). Read the angle SCB = 120° and add to 180° (representing the straight angle NCS = half a complete turn). This gives 300° as the bearing of the bridge from the church.

Note that all bearings must be reckoned clockwise from the north.

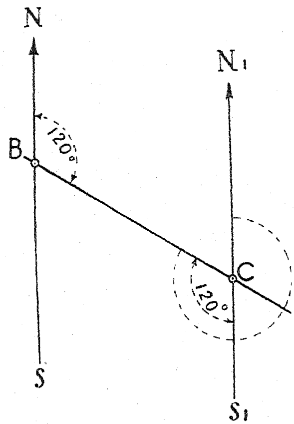


Fig. 72. ILLUSTRATION OF BACK BEARINGS AND THE CONVERSION OF FORWARD INTO BACK BEARINGS.

Through C draw N_1CS_1 parallel to NS. Forward bearing of C from B is 120° (*i.e.* angle NBC). Forward bearing of B from C is reflex angle N_1CB = 300°, but this is the back bearing of C from B, and is equal to 180° + 120° (*i.e.* 180° + angle BCS_1).

Because N_1S_1 is parallel to NS, angle BCS_1 = angle NBC. This can be applied to Fig. 71.

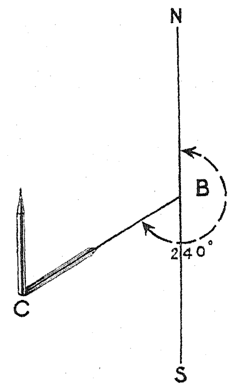


Fig. 73. TO FIND THE NS LINE FROM THE SUN.

Let NS be the north-south line. If it is 4 p.m. o'clock make the angle NBC 240° (15° for every hour after midnight). At C hold pencil vertically, rotate map until shadow of pencil is shown on the line CB, then NS is in true position.

3. METHODS OF SETTING A MAP

(1) BY COMPASS.—This is the most satisfactory method and should always be used when a compass is available. Lay the map flat on the ground and place the compass on it close to the magnetic meridian printed

in the margin. Then turn the map gently until the magnetic meridian is lying parallel to the compass needle. If there is no magnetic meridian on the map proceed as above, using the map edge as the meridian. Turn the map until the edge lies parallel to a bearing of N. 10° E. (assuming the variation to be 10° W.).

(2) BY THE SUN.—If no compass is available and the sun is shining the map may be set by it. In Britain the sun is approximately south at noon, roughly east at 6.0 a.m., and roughly west at 6.0 p.m. (Add one hour to these times when summer time is being kept.) Assuming the bearing of the sun changes at a uniform rate (this is far from true), it will bear, very roughly:

East at 6.0 a.m.	S. 45° E. at 9.0 a.m.	South at Noon	S. 45° W. at 3.0 p.m.
S. 75° E. ,, 7.0 ,,	S. 30° E. ,, 10.0 ,,	S. 15° W. ,, 1.0 p.m.	S. 60° W. ,, 4.0 ,,
S. 60° E. ,, 8.0 ,,	S. 15° E. ,, 11.0 ,,	S. 30° W. ,, 2.0 ,,	S. 75° W. ,, 5.0 ,,
			West ,, 6.0 ,,

If the map is flat and horizontal the shadow of a pencil held vertically on it will lie on the back bearings of the above, *i.e.* N. 45° W. at 9.0 a.m. and N. 45° E. at 3.0 p.m. The above assumptions are so approximate (*e.g.* only at the equinoxes is the sun east at 6.0 a.m. and west at 6.0 p.m., and even then its bearing does not change uniformly)[1] that it is a waste of time to plot the back bearing accurately with a protractor (see Fig. 73) and it is just as accurate and more simple to use the watch instead. Place it horizontally on the map with the small (hour) hand pointing at the sun (see Fig. 74). Then the line from the centre of the watch to a point midway between the hour hand and twelve o'clock will point approximately south along the true meridian. Note the point on the horizon to which this line points and turn the south part of the map towards it.

(3) BY COMPARING LONG, STRAIGHT FEATURES WITH THE MAP.—If no compass is available and the sun is not out the map can sometimes be orientated or set by noting the direction of long, straight features, such as the road or railway from Draycott to Cheddar, shown on the map facing p. 138, and then turning the map until the features on the map lie parallel to

[1] The change is about 18° for the hours either side of noon and about 12° for the hour after 6.0 a.m. or before 6.0 p.m. Longitude, latitude, and a variable factor known as the "equation of time" are other causes of uncertainty.

those on the ground. This method can be very accurate if the straight features radiate from the observer, but when they are broadside on there is much uncertainty.

(4) By Comparing Features in the Field with their Representation on the Map.—As an alternative to (3) the map may be set by "pointing" it at features which can be identified in the vicinity, particularly when two of them are in line, or nearly so, with the observer. As an example, suppose

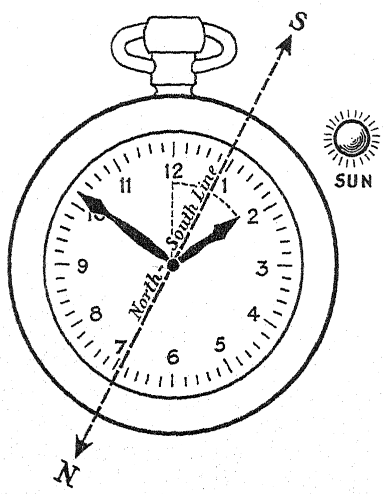


Fig. 74. To Find by Watch South in Northern Hemisphere.

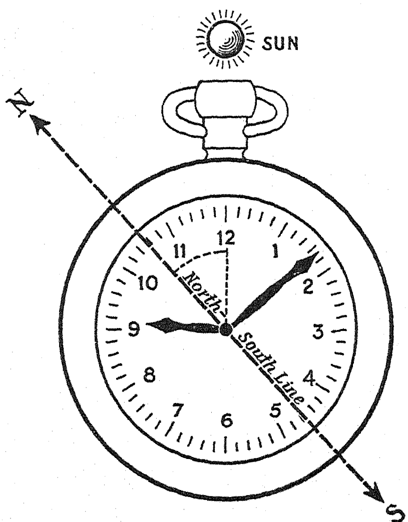


Fig. 75. To Find by Watch North in Southern Hemisphere.

an observer somewhere in the marshes south of Lewes (see map facing p. 148). First a spire is seen which must be either Iford or Rodmell church; as another spire is seen well to the left it must be Iford. The map is turned to point at the two churches. The large building midway between the two is now identified as Northease Farm and further, the shoulder of Front Hill is immediately behind it; this gives a "leading line" and another is sought roughly at right angles to it, and found when it is noticed that Swanborough

Manor is just to the right of Iford church; drawing these leading lines on the map with faint pencil lines their intersection shows the position to be on grid lines 42 E. and 07 N. If any doubt still remained it could be resolved by walking north-westwards until the lane leading to Northease Farm was struck.

In country where there are many distinct features this method of setting the map and identifying the position is comparatively simple, but in open moorland country when no clearly defined features are in sight identification can be very difficult. In such country no field worker should ever be abroad without a compass. It should be remembered, especially when going across country, that an approximate position can always be estimated if the rough direction and rate of travel from the starting point has been noted.

CHAPTER XI

THE PHYSICAL BASIS OF MAP READING

The relief of a region is a key to its physical geography, and this helps to explain much of the human geography. Contours show the position of mountains and hills, their general outline, and their height. A knowledge of the lie of the land helps us to understand the direction and character of the drainage and to appreciate modifications in the climate, especially rainfall and temperature conditions.

Various features of relief have profound effects on man: the slope of the ground, the direction of a valley, the shelter of a cliff—these and many others may decide whether man's settlement is exposed or sheltered, swampy or dry, protected or liable to attack, difficult to approach, or accessible to neighbouring communities, and so on.

To appreciate these factors we must be able to read the contours and to say with certainty what features they represent. Certain features are common to mountainous and hilly land and can be identified on the map by the shape and trend of the contours. [Broadly speaking, a mountain is land whose highest point is over 3,000 ft above the surrounding country. Land whose summit is less than 3,000 ft above the surrounding country is a hill. A low, detached rise may be called a knoll whether it be on a plateau or on lowland, as drumlins, for instance (p. 112).] Remember to try to build up in your mind a three-dimensional view of the area shown on the map.

A good exercise which will emphasise the meaning of contours is to make a separate tracing of, say, the 100-ft contour on a sheet of cardboard, soft-board, or thin two-ply wood and to cut round the contours with a fine saw. Do the same with each of the other contours, and place the pieces of cardboard or wood one on the other in their proper sequence. Thus you have a model of the country. Plasticene may be used to round off the sharpness of the contour edges. A fairly elaborate model can be made by inserting the streams in blue pencil, and by using suitable colour wash for

the various features, for example, green for woodland or pasture, brown for arable land.

1. HILL FEATURES AND RIVER VALLEYS

Let us consider various features of hill country as shown in Fig. 76. *A*, for instance, is a detached *conical hill* whose contours show us that it rises regularly up to 400 ft in height. Above 400 ft, in the absence of a spot height, it is impossible to determine whether this is a small flat-topped hill, or whether it continues to rise up to a point just short of 450 ft.

Point *B*, in Fig. 76 is situated on a *plateau*, also lying above 400 ft, on which is a triangulation station, whose height was determined with great

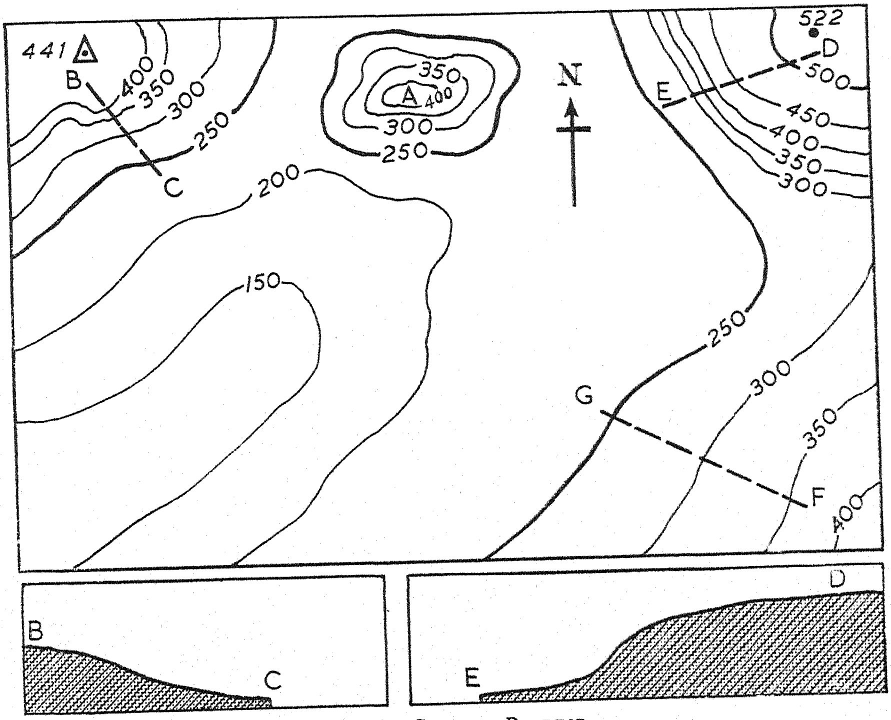


Fig. 76. Contour Reading.
To appreciate the different slopes try to visualise the relief shown in three dimensions.

accuracy as part of the survey of the country. South-west from *B* the plateau falls to a valley in a *concave slope*, whose cross-section along the line *BC* is shown below. Notice that the contours are at first close together, but then becomes further apart as the slope lessens.

Point *D* lies to the north-east, near a spot height of 522 ft (this height above sea level having been accurately determined). From *D* to *E* the slope is a *convex* one, as illustrated by the cross-section below, the contours being

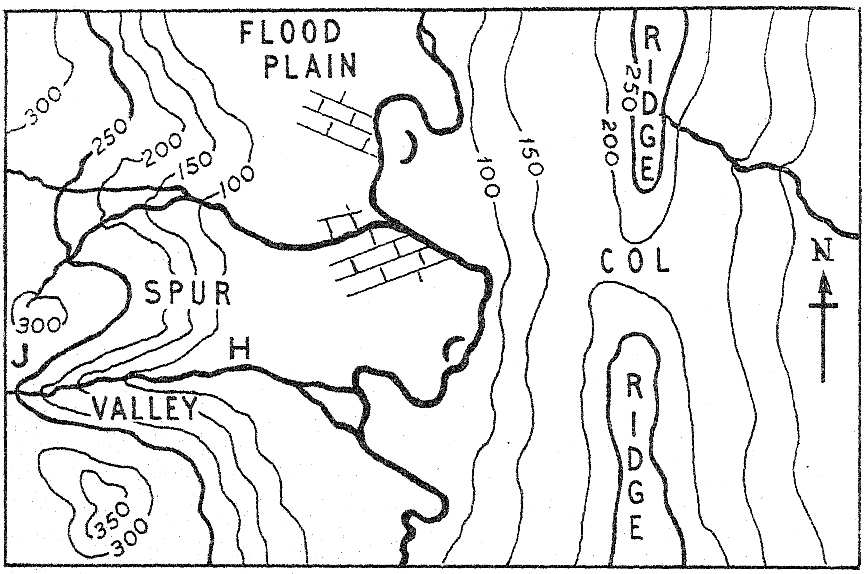


Fig. 77. CONTOUR READING.
Some common features in hill country.

at first fairly far apart but becoming closer together as the slope increases. From *F* in the south-west the land slopes evenly down to point *G*, the contour here being regularly spaced, and fairly far apart, so that the slope is a gentle one. The lie of the 200 ft and 150 ft contours shows a fall to the south-west down a *broad valley*.

Fig. 77 shows some of the more common relief features found in hilly country. Here there is ready surface drainage from western hills to a broad

valley, which is bounded on the east by high ground rising to a *ridge*. Notice the *col*, sometimes called a *saddle*, which dips down between the higher parts of the ridge, yet with lower ground still on either flank.

Along a river valley the distance between the contours normally increases from the source to the mouth, as the valley flattens out—though one should look for irregularities in the course of the stream and in the valley profile, and try to determine their cause—perhaps changes in the nature of the underlying rock, or perhaps the effects of former glaciation. In general, a young river cuts a *V-shaped valley*, whose contours are of the type seen between J and H in Fig. 77. The Vs formed by the close contours point upstream. A more mature river-cut valley is wider and more nearly U-shaped, and usually has fairly well-defined spurs.

Features of the flood plain of the main river are also shown in Fig. 77. The river *meanders* along the main valley, whose fall is slight. Here are *ox-bow lakes*, *braiding*, and man-made *drainage channels*, and at points the river cuts into the ridge, enlarging its valley.

2. DRAINAGE PATTERNS AS A GUIDE TO STRUCTURE

A careful examination of the way in which the rain falling on the countryside is dispersed and distributed tells us a great deal about the structure of the land. On hard, *impervious rocks* in a moist climate the run-off is rapid, and the many young streams in an upland area tend to cut deep valleys and form part of a well-defined drainage pattern. If the rocks are hard, their Vs will be relatively deep and narrow; if the rocks are soft the valleys will be wider and shallower. Examples are seen in the Lake District where the hard rocks minimise the tendency of the heavy rainfall to wear away the sides, so that steep-sided valleys result.

There is usually less surface drainage on *pervious rock*, and the streams usually appear at the surface further away from the watershed, and sometimes disappear from the surface further down-stream. Dry valleys, or bournes, which contain water only when the water-table is particularly high, are features of porous rocks, especially on the chalk downlands of southern England. A harder, jointed rock, like limestone, which absorbs water through the joints and surface cracks, may be heavily eroded both by corrasion and by solution, but allow little lateral erosion, so that valleys are narrow and steep-sided (see O.S. 1-in. map of Cheddar).

Relief and water features are, then, intimately connected, and one of the first things to do in studying a map of a new region is to examine the drainage system. The term watershed should be fully understood, and Fig. 78 helps to illustrate its meaning. In any country, even in areas where the slope of the land is difficult to determine, there may be two or more completely separate drainage systems. The divides between them are usually more obvious in hilly or mountainous country, though this is not always the case.

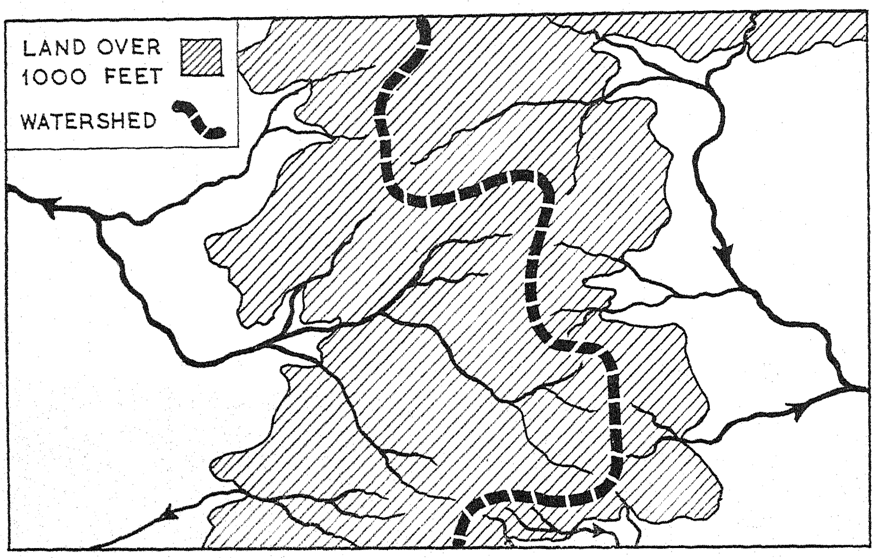


Fig. 78. THE WATERSHED.
The way in which water runs off the surface and the line of the watershed can tell us a great deal about the relief and structure—even where few contours are shown.

The *watershed*, or water-parting, then, is the highest part of the land which separates one stream system from another.

A special form of upland feature, with a characteristic drainage pattern is an *escarpment*. Fig. 79 shows how such a feature appears on a contoured map. The contours are close together where the steep face of the scarp overlooks a vale to the west. The wide spacing of the contours to the east shows that here the escarpment slopes gently down as a "dip-slope".

Because of the ridge-like nature of the watershed, the streams on the dip-slope make their appearance well away from the scarp face. This feature is typical of the stretches of chalk and Jurassic limestone in Britain especially on porous rocks, though broad valleys may run eastward from the very edge

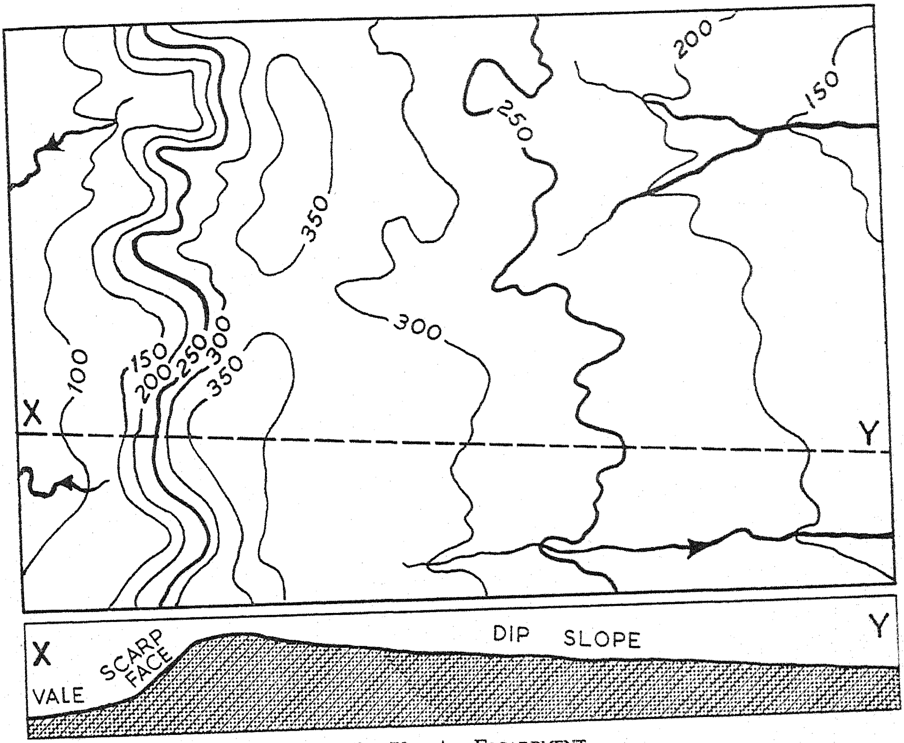


Fig. 79. AN ESCARPMENT.
A typical feature both of the Jurassic limestone and the chalk of southern and eastern England.

of the escarpment, relics of water courses in the days when the escarpment extended further to the west (in our Fig. 78) or of a wetter period.

In some examinations candidates are asked to suggest suitable physical or physiographic divisions. A study of the distribution and nature of the streams and rivers and their valleys is essential, and it may be a good plan

to make a tracing of the streams and another of selected contours. After separate examination, place the stream tracing on that of the contours and examine them together. This is particularly useful on lowlands where the drainage is ill-defined.

3. FEATURES DUE TO GLACIATION

Over most of the British Isles relief features show the effects of glaciation, even those south of the main ice sheets, where the results of the outpouring

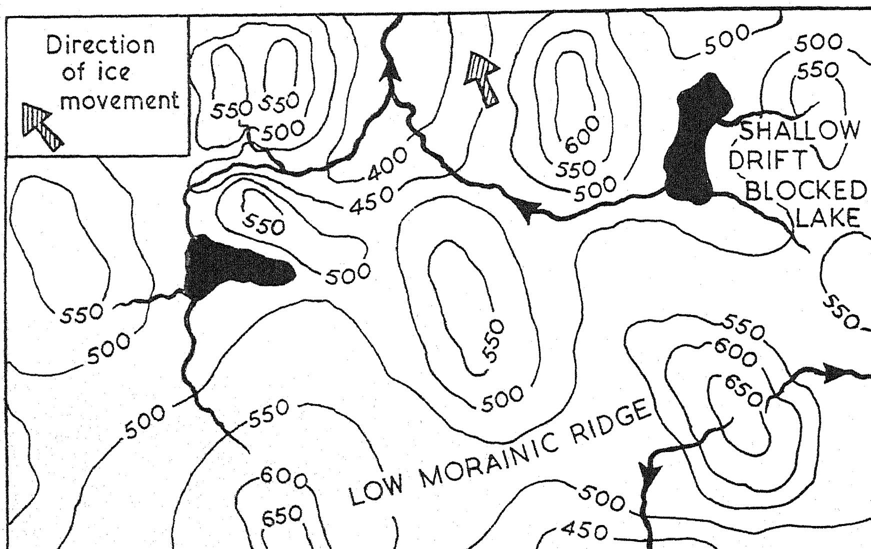


Fig. 80. The Representation of some of the Features of Lowland Glaciation (moraine deposits, drumlins, drift-blocked lakes, and interference with natural drainage).

of melt water may be seen in a mantle of debris or in valleys carved by the water itself. We should, therefore, be able to recognise typical glacial features on both highlands and lowlands by examining the contours of glaciated areas.

Fig. 80 shows some of the features to be seen in a *glaciated highland region*. In many upland areas the hills themselves have been smoothed by glacial action, so that the contours are seen to be well spaced on the

summits of the hills. In more mountainous regions, however, ice action may have been confined to the valleys and lower slopes, and above these the peaks stand out boldly, their jaggedness emphasised by frost shattering (though this is more to be seen in true alpine country than among the mountains of Britain, which show rather the effects of *ice-smoothing*).

Notice in Fig. 81 the *corrie lakes* or tarns *AA*, with the steep walls of the corrie behind and the arm-chair appearance. Tarn *B* spills its water down a *hanging valley*, suspended above the main lake-filled valley in the north-west. These long *ribbon lakes* occupy valleys which can be seen to be U-shaped. Present day streams carry silt, which may eventually fill up the ends and, sometimes, the middle of the lakes (see the $2\frac{1}{2}$-in. map of Keswick opposite p. 142). Deep ribbon lakes may sometimes have under-water contours marked in blue on Ordnance maps. Where corries lie head-to-head or where glaciated valleys run parallel to one another and close together, a narrow ridge or *arête* separates them (*CC* on the map).

Features of *deposition* and *ice-scooping* may be recognised on a *glaciated lowland*, though some revealing results of glacial action will not be seen—where, for instance, low *roches moutonnées* and other ice-plucked and scratched rocks are of insufficient height to affect the contours, and the same applies to erratics and low moraines, eskers, and drumlins. Examples of the latter, on the other hand, are often easily identified, as are the effects of glacial deposition on the drainage. *Eskers* and *drumlins* can be identified, for instance, on the $2\frac{1}{2}$-in. Ordnance maps of the Eden Valley and lowlands in Cumberland, and on many sheets in Northern Ireland. Fig. 81 shows the appearance of drumlins on such a map, and the disruptive effect they may have on drainage. The direction of movement of the ice-sheet is indicated by the direction of the long axis of the drumlins and by the overall slope of the land. Where more localised deposits of *glacial moraine* have interfered with river courses the result may well be easy to see on the map, but not easy to attribute to ice action unless one has prior knowledge of the nature of the deposit. The Yorkshire Derwent is deflected in this way by a moraine. It formerly flowed to the North Sea, but is now forced to take a westward course of about one hundred miles to join the Yorkshire Ouse.

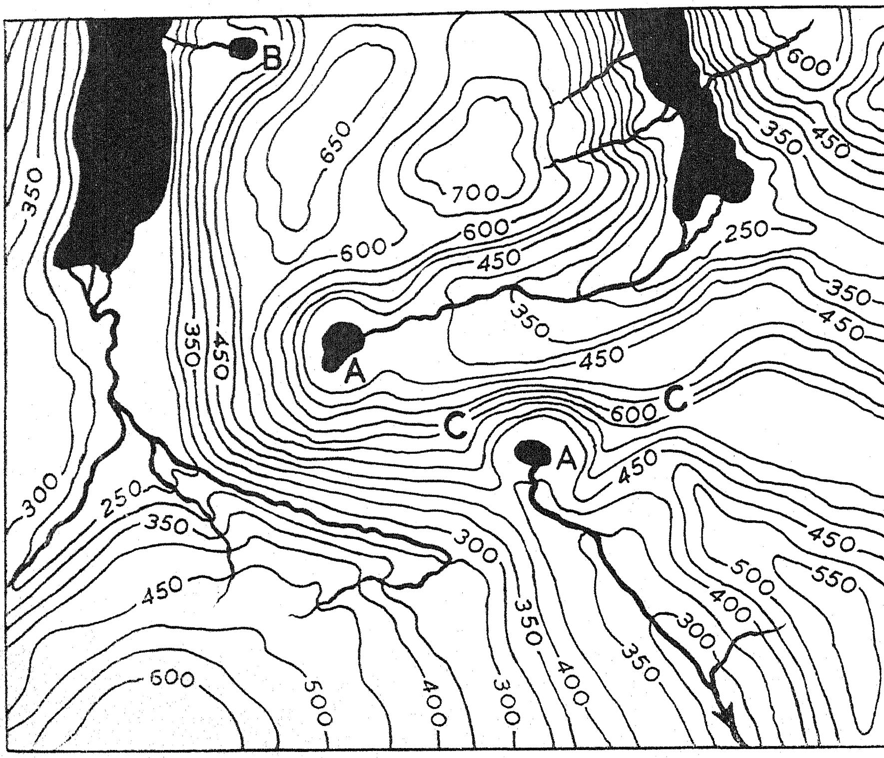


Fig. 81. The Representation of some of the Features of a Glaciated Highland.

4. PLACE-NAMES AND PHYSICAL FEATURES

The place-names themselves merit a careful study, and it is as well to learn something of their origin. Each of the peoples who have successively occupied the various parts of the British Isles have left traces of their occupation in the names they gave to the objects around them, and which can still be traced in the place-names of to-day. The lists which follow are by no means comprehensive, but are examples of the names used by the various peoples to describe features which we can recognise to-day. It is useful to make a fuller list of your own, which you can add to, and which will help topographical interpretation.

EXAMPLES OF PLACE-NAMES INDICATING NATURAL FEATURES

CELTIC—

Aber	confluence of waters, a mouth.
Ath	ford.
Avon	water, stream, river.
Ben	mountain.
Bryn	hill.
Burn	small stream.
Carrick	cliff.
Coire, cuire, corrie	hollow, ravine.
Craig, carig	rocks, stones.
Cwm, combe	valley.
Dwfr	water.
Glan	shore, bank.
Gweath, gwith	trees.
Inver	mouth, confluence.
Nant	stream.
Pen	peak, hill-top.
Pwl	marsh, pool.
Rhos	moor.
Scawen	elder tree.
Strath (Ystrad),	an extensive valley.
Tor	high rock.

Find examples of these from maps of Scotland, Wales, Ireland, the Lake District, Cornwall, *e.g.* place-names containing such descriptive words are: Aberavon (meeting of waters), Athlone (ford of St Lucas), Craigmore (a large rock), Trengweath (a village among the trees), Penrhyn (head of the promontory), Kirriemuir—from Corriemor—(a great hollow), Boscawen (house by the elder tree).

ANGLO-SAXON—

Beck	small stream.
Bourne	seasonal stream.
Den, dene	deep wooded valley.
Ford	(modern meaning).
Holt	wood
Hurst	wood
-ing	an affix showing an important settlement, or sometimes a grassy meadow.
Law, low	hill
Moed, mead	meadow.
Sal, sael	willow.
Wad, wath	ford (wading place).

These are but a few. Many of our modern descriptive names were used in Anglo-Saxon times in almost the same form (*e.g.* "hill"). Examples of place-names with descriptive words are: Winterbourne (a stream flowing only in winter), Croxden (valley of the cross), Watford (ford on Watling Street), Aldershot—or Aldersholt—(alder tree wood), Godalming (Godhelm's meadow), Ludlow (the people's hill).

DANISH AND SCANDINAVIAN—

Dahl, dale	valley.
Ey	island.
Fell	high mountain.
Gill	ravine.
Holm	small island.
How	mound.
Lythe	slope.
Ness	promontory.
Rigg	ridge.
Scarth	pass.
Skaer	sharp rock.
With	wood.

Examples of these include: Romney (marsh island), Rydal (rye valley), Dungeness (danger cape), Scarborough (settlement beneath a promontory).

NORMAN—Few names in this category are specifically of Norman origin, though occasionally we find descriptive names like Beaulieu or Malpas.

5. INTERVISIBILITY

It may well be of practical value to assess whether one point on the ground is visible from another. To do this we must consider the changes of slope between the points. This can be done by examining the contours, by comparing the gradients or by drawing a section from the contoured map.

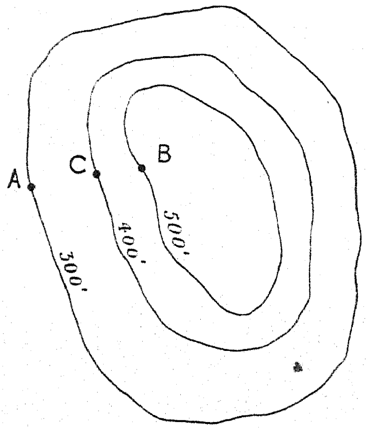


Fig. 82. TO DETERMINE VISIBILITY BY COMPARING GRADIENTS.

BY CONTOURS.—Examine the contours to see whether the slopes are convex or concave. Barring minor features, trees, and high buildings, which may obstruct the view, two points on a concave slope (see Fig. 83*b*) are mutually intervisible, while two on a convex slope (Fig. 83*c*) are not.

BY COMPARISON OF GRADIENTS.—The method of determining visibility by comparison of gradients is best explained by reference to practical cases exemplified by Fig. 82. Careful examination of the contoured map is needful to identify the lower and higher of the two points with which we are concerned. It is also necessary to know the distance between the two points, which can be determined by using the scale of the map. Some break of slope intervening between the two points must be utilised.

Example. Consider Fig. 82. Is A visible from B?

Let C be a break of slope along the 400-ft contour, and 600 yd (*i.e.* 1,800 ft) from B and 650 yd (*i.e.* 1,950 ft) from A. Therefore A is 1,250 yd (*i.e.* 3,750 ft) from B.

$$\text{(1)} \quad \text{Gradient from } A \text{ to } C = \frac{100}{1950} = \frac{1}{19{\cdot}5}$$

(*i.e.* V.I./H.E., because **gradient** is ratio of Vertical Interval to Horizontal Equivalent).

Note. The Vertical Interval is the difference between two successive contours; the Horizontal Equivalent is the horizontal distance between two successive contours (Chapter III).

$$\text{Gradient from } A \text{ to } B = \frac{200}{3750} = \frac{1}{18{\cdot}75}.$$

As gradient from A, the lowest point, to the break of slope C is *less steep*[1] than from A to B, the points A and B are mutually visible.

$$\text{(2)}\quad \text{Gradient from } C \text{ to } B = \frac{100}{1800} = \frac{1}{18}.$$

$$\text{Gradient from } A \text{ to } C = \frac{100}{1950} = \frac{1}{19{\cdot}5}.$$

As gradient from A, the lowest point, to C is *less steep*[1] than from C to the highest point B, the points A and B are mutually visible.

From the preceding argument we can deduce the following rules:

(1) Find gradient x from the lower point to an intervening break of slope, and gradient y from the lower to the higher point. If x is steeper than y the points are mutually invisible, but if x is less steep than y they are mutually visible.

(2) Find gradient x from lower point to an intervening break of slope, and gradient y from this break of slope to the higher point. If x is steeper, the points are mutually invisible; if x is not the steeper, they are mutually visible.

BY DRAWING A SECTION.—To draw a section is a reliable method unless some unknown under-feature intervenes. A section is a profile drawing of the elevation given by cutting vertically downward through a model of the features.

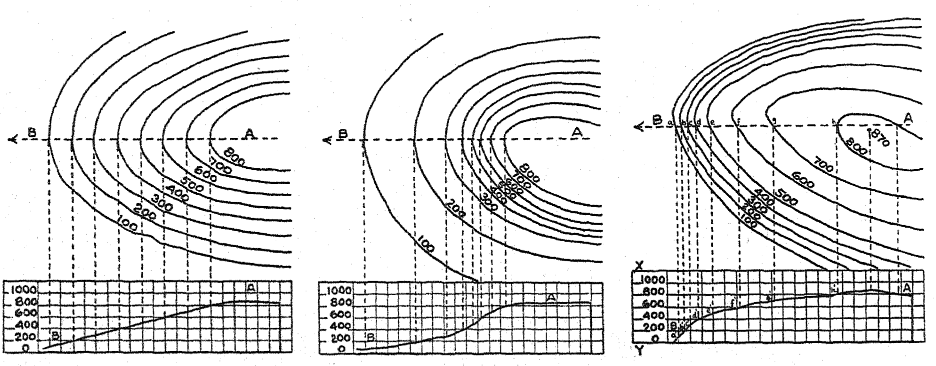
Example. Consider Fig. 83. The line AB represents the line of the desired section. It cuts the contours at certain points, a, b, c, d, etc. Take a piece of paper, here represented by the squared-paper, and place below the contoured map, marking on this paper a vertical scale XY, 100 ft,

[1] If this gradient had been the steeper, in each case the points would have been mutually invisible.

200 ft, etc., to correspond with the contoured intervals. Drop perpendiculars from the points a, b, c, etc., in AB to meet the horizontal lines marked 100 ft, 200 ft, etc., on the vertical scale XY, giving positions a', b', c', which, when joined, will represent the required profile.

Such profiles are approximate, and in some sense guesswork, as minor features may occur between contours and thus are not represented on the contoured sketch. However, spot heights may sometimes give greater accuracy to a profile if they are wisely used as guides when they occur on the top of a ridge, etc.

When using a map, it is often inconvenient to draw lines on it as when



(*a*) Uniform. (*b*) Concave. (*c*) Convex.

Fig. 83. Slope of Spur.

drawing a section by this method. The points of intersection of the contour lines with the section line should, therefore, be first marked off and numbered along the edge of a spare piece of paper held carefully along the section line (see Fig. 84). These points are then transferred to the base-line of the section drawing, and perpendiculars erected to meet the corresponding horizontals of the correct height (Fig. 85). The section is then drawn in as before.

Sections should always be joined by a freehand line, which is completed beyond the last contour cut by the section line by continuing it without sharp change of direction to the end of the section. In doing this, care must be taken not to exceed the V.I. The west or north end should be on the left of the completed section, which should carry the title, direction, and

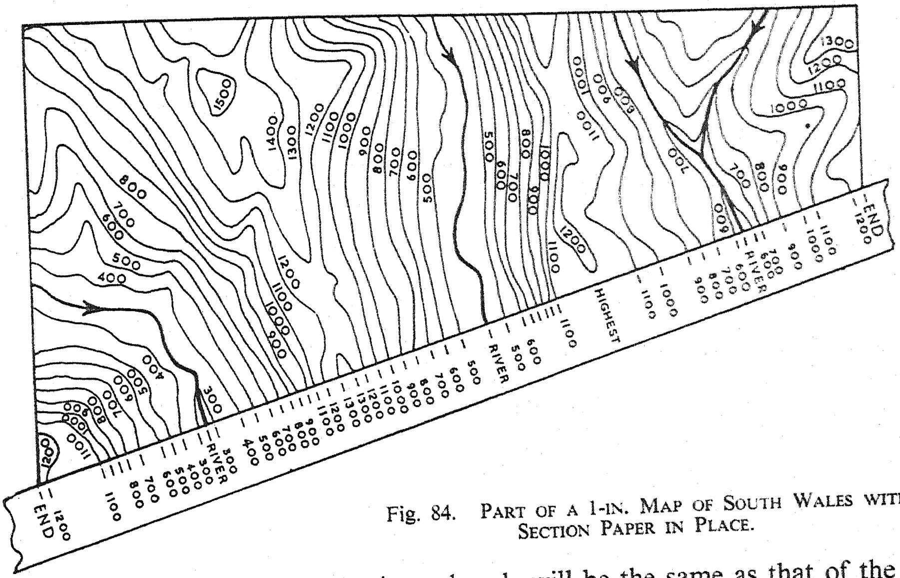


Fig. 84. PART OF A 1-IN. MAP OF SOUTH WALES WITH SECTION PAPER IN PLACE.

scales of the section. The horizontal scale will be the same as that of the map from which it is drawn. The vertical scale should be such that it does not give an exaggeration exceeding about five times for a 1-in. map, even in fairly level country. For steep slopes, on this scale, it is often possible to draw sections true in both scales. For small-scale maps, however, even greater exaggeration is permissible.

A profile of a road can be made by marking the points of intersection of contour lines with the road, in each straight section, along the paper edge. Changes of direction should be noted here and transferred to the finished section.

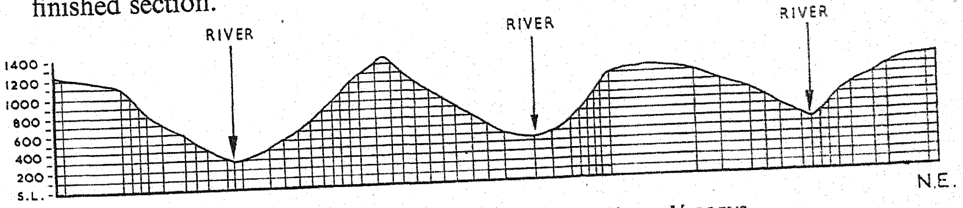


Fig. 85. SECTION ACROSS THREE SOUTH WALES VALLEYS.
Horizontal scale 1 in. to the mile. Vertical scale 1 in. to 2,000 ft. Vertical exaggeration 2·6 times.

EXERCISE III

1. On the map (Fig. 86) given you, contours are drawn for every 250 ft.
   (i) Draw in neatly (*a*) the course of the stream which enters the sea near *A*; (*b*) its chief tributaries.
   (ii) What is the approximate height of the highest point of the island? Mark its position by an arrow.
   (iii) Calculate the approximate scale of the map, and explain how your result is obtained.
   (iv) Calculate the average slope from *B* to *X*.
   (v) Compare the view obtained from *X* with that from *Y*, looking east in each case.

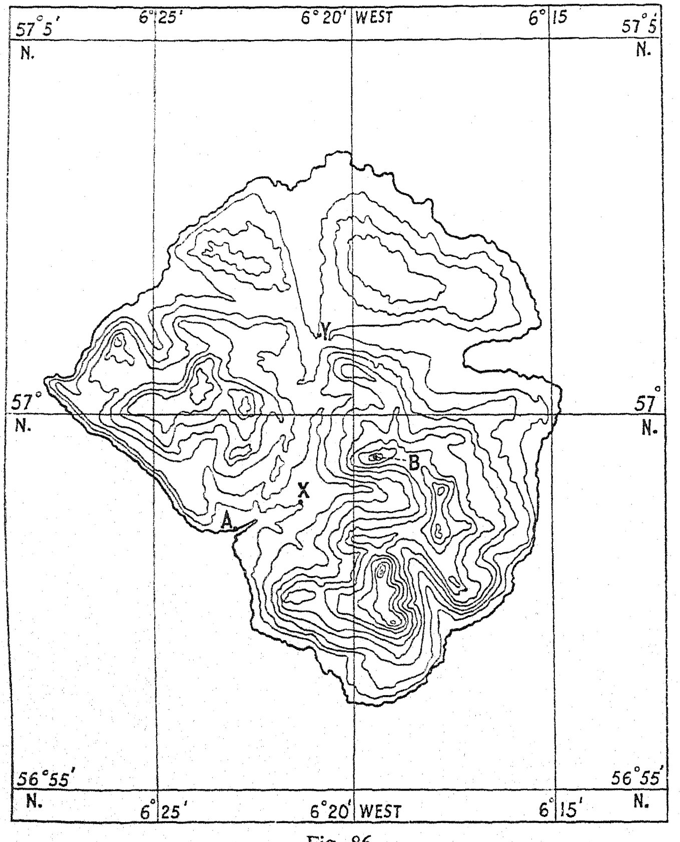


Fig. 86.

2. Enlarge the map (Fig. 86), say to twice the size, and draw the contours in pencil. Identify the valleys and trace in ink the course of probable streams.

3. Write notes on the physical characteristics of the valleys as suggested by the contours in Fig. 86, *e.g.* what you could learn from longitudinal and cross-sections, etc.

4. Identify features such as escarpment, spur, ridge, plateau, col in Fig. 86.

5. Suggest the types of scenery noticeable in a coasting voyage round the island (Fig. 86).

6. The map (Fig. 87) is drawn on the scale indicated below. Contours are drawn at 100 ft, at 200 ft, and upwards for every 200 ft.

(*a*) Shade lightly in pencil the parts between 800 and 1,000 ft.

(*b*) Part of the course of a stream is shown flowing at *A* into the large estuary. Draw in from their sources the courses of the headwaters of this stream.

(*c*) Towards the north-west of the map, the mouth of a stream is shown flowing into the sea at *B*. Draw in pencil the water-parting (*i.e.* the divide) of the basin of this stream, as far as it is shown on the map.

(*d*) *Either:* Compare the views to the east and to the west from the commanding position at *Y*. Remember that your field of vision is about 60°;

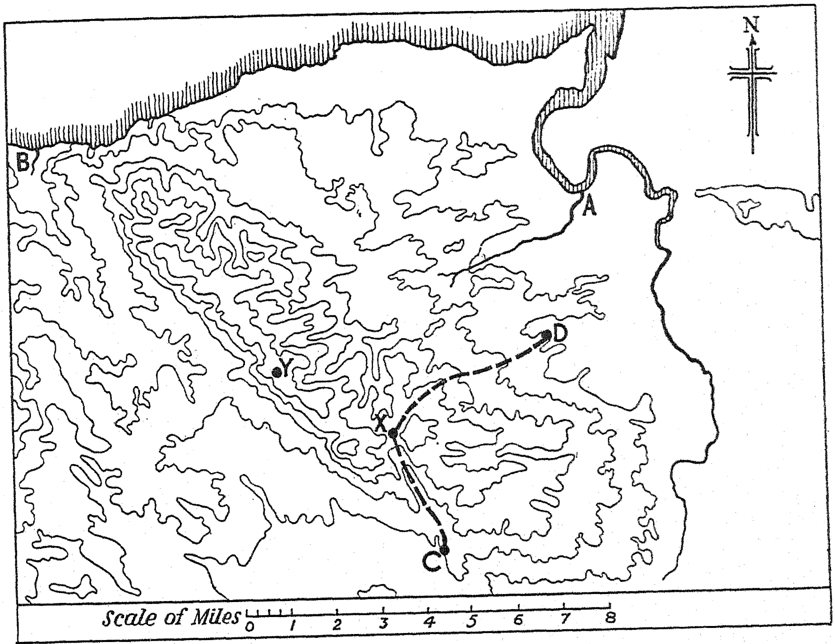


Fig. 87.

Or, Describe the direction and character of the small road, indicated by a broken line (- - - - -) from *C* to *D*, through *X* (750 ft), and calculate the gradients in the steepest parts on either side of *X*.

7. In Fig. 87. (*a*) Identify the various physical features by means of the contours. (*b*) Describe the features associated with the large river flowing northward into the sea. (*c*) Describe the character of the coastal lands. (*d*) Compare the coastal plain with the flood-plain of the river noted in (*b*).

8. Study the map given in Fig. 88. It is contoured at vertical intervals of 100 ft, and shows all the surface streams of the area.

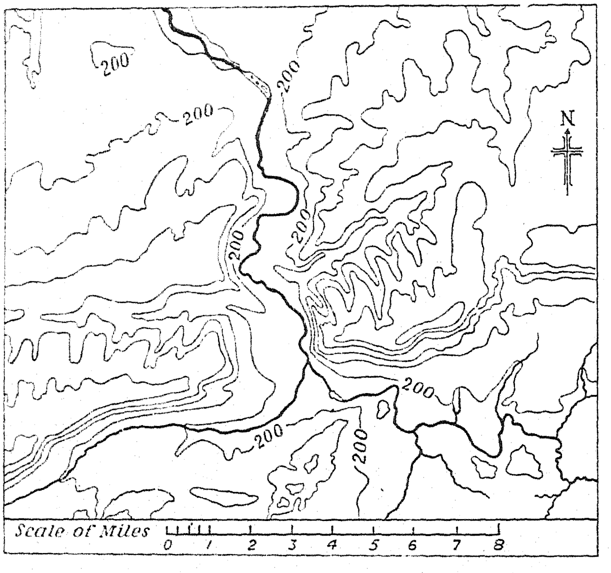


Fig. 88.

(*a*) Calculate the approximate area in square miles of the country shown on the map.

(*b*) Shade the parts more than 600 ft above sea level.

(*c*) Print the words "gap", "escarpment", and "dry valley" in their appropriate places on the map.

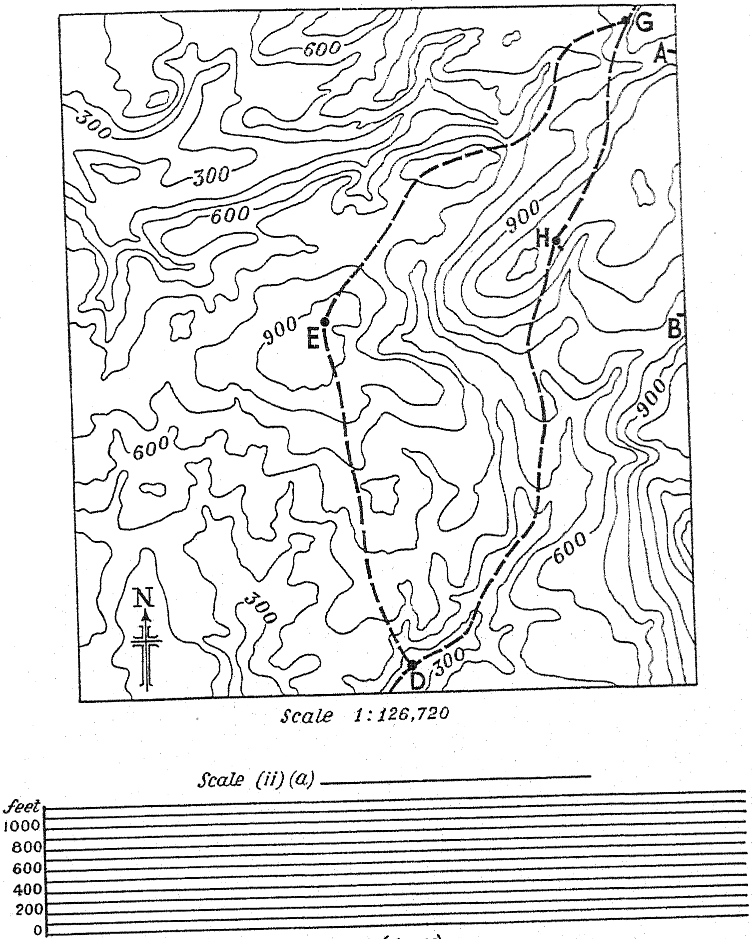
(*d*) Describe the chief features of the relief of the land.

(*e*) Two railways traverse this area, one from north to south, the other from west to east. Insert them on the map.

9. Describe the features associated with the river shown on the map (Fig. 88), and compare the character of the valley at different parts of its course.

10. Compare the streams in the south-east of Fig. 88 with that in the south-west, and make some comparison of the landscape likely to be seen in different parts of the region mapped.

11. Enlarge the map (Fig. 88) to three times its present size (see p. 12), and draw three or four diagrams showing cross-sections of the valley at different points. Describe any differences in the type of valley shown by such sections.



(ii) (c) Distance in miles from D to G (via H) =

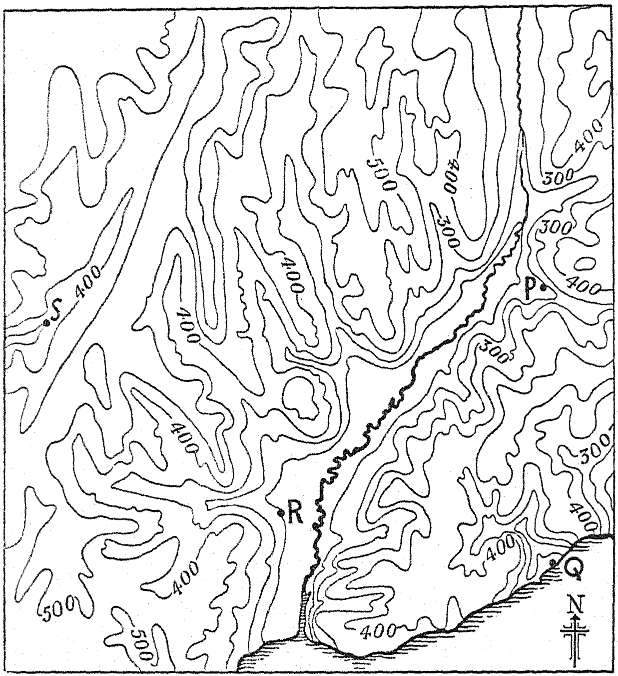
Fig. 89.

12. Suggest where, on Fig. 88, village sites are, and are not, likely. Suggest any negative effect of the river on location of village sites and say what use would probably be made of the land in the main valley.

13. The area shown on the map (Fig. 89) is taken from a British Ordnance map. The contours are drawn at intervals of 100 ft, and the dotted lines represent roads.

(i) On the map mark the following:

(*a*) A river flowing from *B* to the southern edge of the map, and *one* right-bank tributary.



Scale 1 : 126,720

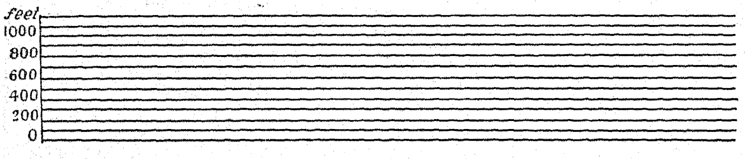


Fig. 90.

(*b*) *One* area of moorland and *one* area of meadowland; shade lightly these areas in different ways and print the words **Moor** and **Meadow** on the shading.

(*c*) The road from *D* to *G* through *E* as a first-class road unfenced on both sides where it rises above 700 ft.

(ii) Under the map:

(*a*) Divide the given line to show the scale of the map in miles.

(*b*) On the ruled lines, draw a section (or profile) of the road which runs from *D* to *G* through *H*, using the vertical scale which is marked at the side of the lines.

(*c*) State in miles the length of the road *DHG*.

14. The map (Fig. 90) shows part of the south coast of England. The contours are drawn from sea level at 100 ft intervals. Examine the contours carefully and the positions of the points *P*, *Q*, *R*, *S*.

(*a*) Shade the areas which are 600 ft and over.

(*b*) On the ruled lines draw a profile-section of the country along the line joining *S* and *P*.

(*c*) Draw two right-bank tributaries of the main river.

(*d*) Show the most likely track of a railway from *Q* through *R* to *S*, and mark tunnels.

(*e*) Show the watershed in the south-eastern portion of the map (south of *P*).

15. On the map (Fig. 91) find the towns *A*, *B*, *C*, and study the map-scale.

Contours are drawn at 200 ft intervals, from 600 ft upwards. The broken line marks the divide (*watershed*) of two river basins; altitudes along the divide are shown in feet.

Motor roads lead from *B* to *C* into the next river basin.

Draw on the map—

(*a*) A straight line from *A* to the highest point of the divide, and along the line write (i) its direction from *A*; (ii) the distance, to the nearest ¼ ml., which the line represents.

(*b*) *From their sources*, the headstreams of the river on which *A* is situated.

(*c*) A motor road *with easy gradients* between *A* and *B*, and also a branch of that road to *C*.

(*d*) A profile-section along the divide from south to north.

16. Consider Fig. 91 and—

(*a*) Describe generally the relief and write notes on the more important physical features.

(*b*) Suggest broad physical divisions.

17. Study the map (Fig. 92). The contour intervals are 100 ft. The figures near *X* and *Y* give the height in feet of the river at these points.

Two roads, *A* to *B* and *C* to *D*, cross the region.

(*a*) Shade the parts over 800 ft.

(*b*) Measure the distance *by river* from *X* to *Y*, and find the average fall of the river *expressed in inches per mile*.

(*c*) In what *general* direction is the river flowing?

(*d*) Describe *in detail* the course of the road from *A* to *B*. How does it differ from that of the road from *C* to *D*?

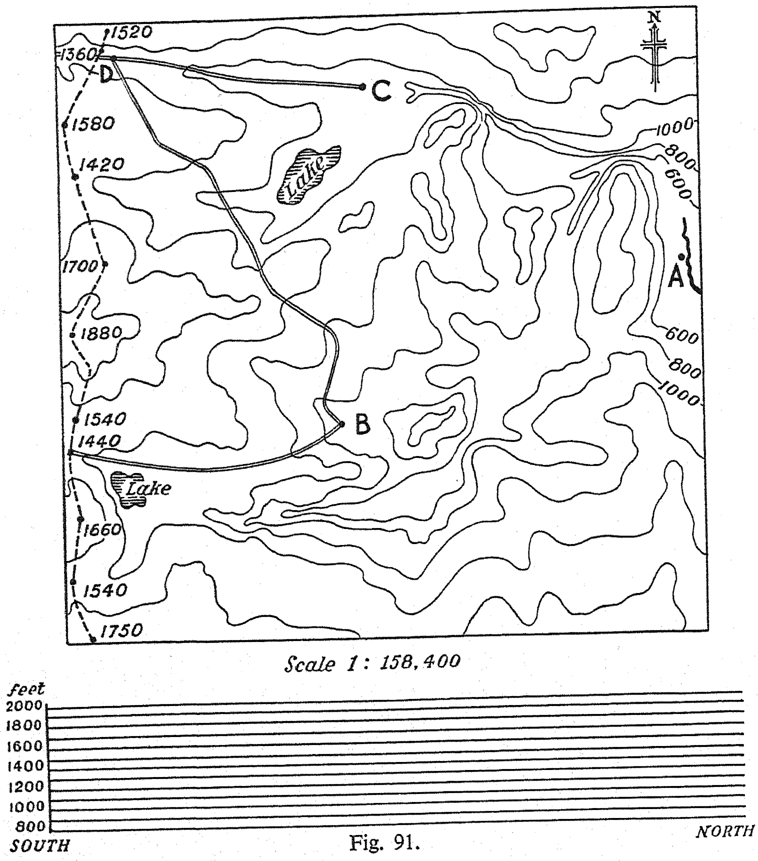


Fig. 91.

18. Consider Fig. 92 and—
   (*a*) Describe generally the relief and write notes on the more important physical features.
   (*b*) Suggest broad physical divisions.

19. Compare the coast lines shown on the accompanying maps (Fig. 93). Describe and explain their characteristic features.

20. Study Fig. 89.
   (*a*) Identify features such as escarpment, valley, spur, ridge.
   (*b*) Attempt a general description of the relief and physical features as suggested by the contours.
   (*c*) Suggest two or three distinctive physical regions, *e.g.* river basin, dissected plateau, etc.

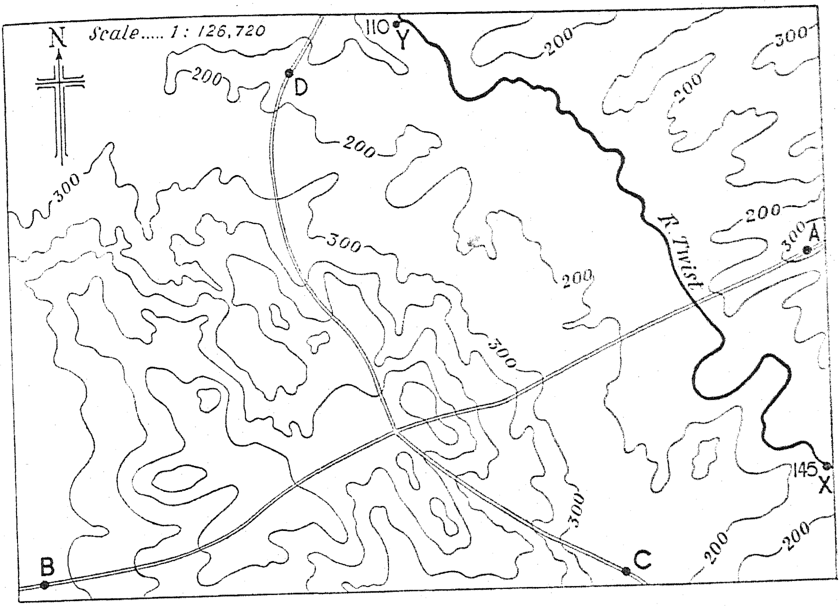

N
Scale..... 1 : 126,720
110
Y
D
200
300
R. Twist
A
145
X
B
C

Fig. 92.

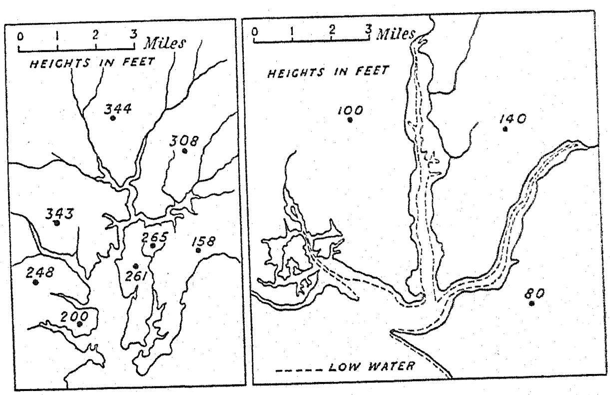

0 1 2 3 Miles
HEIGHTS IN FEET
344
308
343
265
158
248
261
200
0 1 2 3 Miles
HEIGHTS IN FEET
100
140
80
LOW WATER

Fig. 93.

21. Describe and explain the physical features of the regions represented on the maps (*A-D*) (Fig. 94).

What change would take place in *C* if the region were slowly uplifted?

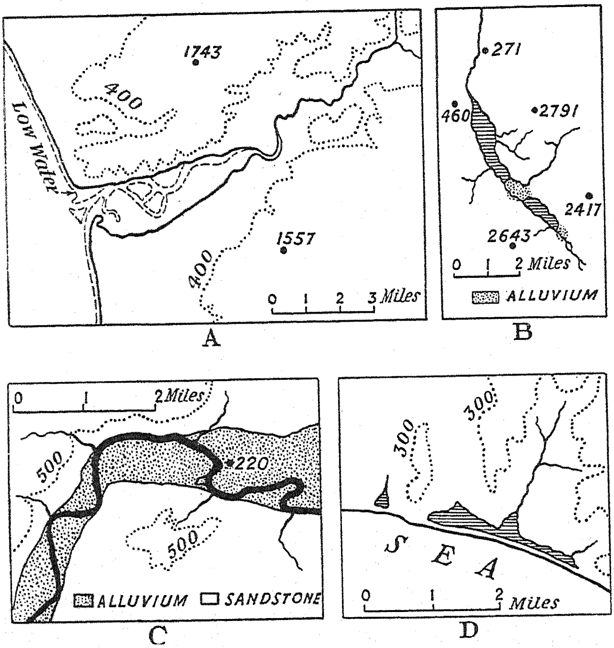


Fig. 94.

22. Consider Fig. 90 and—

(*a*) Identify features such as escarpment, valley, spur, ridge.

(*b*) Attempt a general description of the relief and physical features as suggested by the contours.

(*c*) Suggest two or three distinctive physical regions, *e.g.* river basin, dissected plateau, etc.

(*d*) Describe the coast-land.

(*e*) State what is noteworthy in the course of the river flowing from north to south in the eastern part of the map.

EXERCISE IV

Map Drawing from Data

1. Make sketch-maps with suitable land and sea contours to show the following on a scale of 2 ml. to the inch:

1. (i) A low sandy dune-bordered shore line, with drowned valley estuaries and fringed with low islands. Along the coast the hinterland is flat plain, rising inland to undulating country and finally to chalk upland parallel to the coast and forming a dissected plateau with scarped side furthest from the coast.

(ii) A drowned coast, with fjords and tributaries, fringed by a skerryguard of islands. The land is essentially a plateau about 3,000 ft high, dissected by drainage emptying into the fjord.

(iii) Two roughly parallel east-west ranges of chalk hills about 900-1,000 ft high, with an intervening lowland about 30 ml. wide along which run low hills of sandstone parallel to the chalk ranges. Streams rise on either side of the sandstone ridge and flow towards the chalk, through which they pass by narrow gap valleys to join a large river and the sea coast respectively north and south of this upland region.

2. Draw, stating your scale, contoured sketch-maps to show—

(i) A stretch of inland country about 40 ml. by 30 ml., consisting essentially of chalk uplands with a well-developed escarpment from which streams flow to a bordering lowland. On the upland show examples of ridge and plateau, and give an example of a wind gap. Two consequent streams flow along the gentle slope and unite on the adjacent plain.

(ii) An area of about 50 ml. by 60 ml. showing an alternation of rocky peninsulas and long, narrow openings (rias), the hinterland being an upland plateau dissected by valleys whose streams flow into the rias.

(iii) An island about 40 ml. long from south-west to north-east and varying in breadth from about 30 ml. in the south-west to 10 ml. in the north-east. The south-west coast is much dissected with long, narrow, fjord-like openings and is fringed by a number of small rocky islands. From this coast the land gradually rises to a plateau some 2,000 ft high and stretching through about a third of the length of the island. The plateau descends to a low undulating plain about 15 ml. long by 12 ml. broad. From the plain a range of hills rises to the north-east and is flanked by a coastal plain about 5 ml. wide. From these hills rivers flow to both plains, and also from the plateau to the larger plain. The plateau is of limestone, and the hills, which are of chalk, run down to the coast in the north-east to form cliffs. Much of the smaller coastal plain is marsh, but the larger plain into which two estuaries open, consists mainly of well-drained land on which alluvium predominates. In addition to relief, show drainage features, possible sites of human settlement, and lines of communication.

CHAPTER XII

DEPICTION OF HUMAN SETTLEMENT AND LAND-USE

1. SETTLEMENTS—DISTRIBUTION AND SITING

In map analysis we can often see how geographical factors have affected men and influenced their mode of life and choice of settlement. Site values have changed at different periods, but we can say broadly that in the early days of settlement the main essentials of a good site concerned the need for defence, water supply, nearness to food supplies or the means of producing them. Another important site value was facility for exchanging surplus products with neighbours, so that in the case of towns the command of routeways was of great value, and a bridge town or confluence settlement accordingly important. Later, with the advent of the industrial age, power became an all-important consideration, so that the industrial town and the mining settlement grew up on the coalfield.

Settlements have developed and prospered for many different reasons, and here we can only illustrate a few types. The main thing is that we should learn to look at the map and study the location of the place, its shape, size, and to notice how it fits into the general pattern of settlement. We should then try to obtain some idea of the influence of physical features on the distribution of settlements and on the form of the individual towns or villages. Always ask yourself, "Why is this settlement here, in this particular location?" There may be straggling route villages stretching along a main road as in the Fens, where there are many small holdings, few dominating relief features, and where the road is the line on which the activities of the countryside are dependent for supplies and for distribution of produce. In other regions villages may be grouped about cross-roads, or situated at the end of valleys. In the valleys themselves, where men may find a fertile soil and adequate water supply, the villages are often located on a dry site, on a gravel terrace, or low spur.

The different controls exerted by valleys and hills are very noticeable in Britain. In the Lake District, along the Pennines, and on the Chalk

Downs, there is very little settlement on the higher land. The valleys of the Lake District, whether or not they carry rivers or lakes, account for practically all the settlement, sparse as it is. The extended lines of small villages or hamlets fringe the valleys, where deposits of workable soil are relatively narrow and are often bordered by the steep wall of the valley sides. Hence, the villages extend in a string rather than a group, so that as much land as possible can be assigned to each farm. Sometimes, when conditions are particularly unfavourable, only isolated farms are found, and they are largely based on sheep farming. Such conditions afford striking contrast with the relatively dense agricultural settlement of the fertile Eden Valley.

Around the lakes, larger villages and small townships have a grouped rather than a string-like arrangement of habitations. There is often a deltaic flat at the head of a lake or between two lakes, and these lowlands are more favourable to farming than are the steep-sided valleys. But many of the lakeside settlements cater for tourists during the summer, and their hotels or boarding-houses naturally group round some central focus such as a railway station. Briefly, we may say that the control in the Lake District is mainly relief control, though the heavy rainfall and bleak climate are also unfavourable to settlement on the uplands.

There are plenty of springs, and there is a sufficiency of surface water in the Lake District, but in parts of the Pennines, notably around Ingleborough and north of the Aire Gap in Yorkshire, and in south Derbyshire, the limestone structure introduces an additional negative control, namely lack of surface water. Practically all the permanent water courses are along the valley floors, and in these valleys, known as "dales", are found the human settlements of small villages or single farmsteads, with perhaps a small market town at the entrance to the dale. The upland is mostly heather-covered moor or rough grassland, at best only useful as poor sheep pasture, and frequently not good enough for that. Some parts of the Pennines are composed of impervious rock, notably millstone grit, as in north Derbyshire, and here spongy peat bogs, known as "mosses", are unfavourable to settlement or economic development.

Reference has been made to the importance of lines of villages at the base of the limestone and chalk scarps of south-eastern England. Maps showing parish boundaries in these regions emphasise some important

aspects of soil and relief control. The villages are generally found on the lower slope of the scarp, just above where a permeable rock like chalk or greensand rests on the impermeable clay. This is a zone favourable to springs. The parish boundaries often run from the village in one direction up the hill, giving sheep pasture, and in the opposite direction from the scarp on to the bordering clay vale, which supplies pasture suited to dairying. The shape of such parishes is a long, narrow rectangle. The ploughed land is generally around the village, on soil like the upper greensand of the lower scarp slope, or in the higher part of the clay vale, the lower portions of which may be dotted with single dairy farms. Examples of such parishes are found on the Downs of south-eastern England, Wiltshire, and Dorsetshire, and the limestone heights of Kesteven in Lincolnshire.

As a contrast to the agricultural valleys of England with their sparse farming population, take the densely-peopled mining valleys of South Wales. These steep, narrow valleys enabled coal to be mined in open seams and easily transported to the coast because of a suitable gradient along the valley. But the steepness and narrowness of the valleys is unfavourable to healthy village sites (see Fig. 84, p. 119). Towns and villages are crowded on the slopes, which frequently must be "climbed" by streets, so that houses rise tier above tier. There is lack of gardens, and the upkeep of roads, gas and water mains is heavy, all adding to the costly and drab living-conditions of the miners. Moreover, surface coal is long since worked out, and deep pits must now be used even here.

A town is a complex settlement and the reasons for its development and its multitude of activities are many, and probably obscure to the map-reader. But we can still learn a great deal from a study of its location and site. To take a fairly straightforward case, consider a coastal resort on the south coast of England. Look for the advantages of site, the sea itself, the nature of the beach and its slope, its sheltered position, the way it faces the sun, its rugged or attractive coastal scenery. Then study its communications, its nearness to large urban populations, its room for expansion, and so on. Now study an inland industrial town and look for its advantages of position and site. Consider its industries: their nearness to sources of raw materials, the market available, the ease with which products can be distributed. The map can reveal so much if we study it in a methodical manner.

Tracings should be made of communications and settlements, and studied together and in conjunction with physical tracings. The influence of marshes, streams, rugged relief, etc., can be clearly seen by this method—notice instances of this on the map of the marshy Yeo valley and the Mendip Hills (facing p. 138). The meaning of a nodal town on which routes converge is also emphasised by this method. Notice the position of Cheddar on this same map.

2. LAND-USE—DIRECT INFORMATION AND DEDUCTION

We have already seen that Land Utilisation maps can be studied in conjunction with the 1-in. Ordnance Survey topographical maps. Thus we have a source of *direct information* about the ways in which men have developed the countryside. But there are other ways which are less direct but, in some ways, more revealing, especially from an historical point of view. We should study both the *conventional signs* in connection with settlement and also the *place-names* themselves. Thus reference to hall, manor, farm, marsh, quarry, watermill, windmill, smithy, etc., will afford clues to local activities and land-use. The past is revealed in the form of the names themselves—Celtic or Saxon, Danish or Norman; they reveal past activities almost as clearly as they do the physical features (p. 115). The following lists show once more how useful it is to know the origin and meaning of typical place-names.

CELTIC—

Baile, bally	town or fort.
Bod, bos	home, abode.
Caer	fort, castle.
Les, lis	court, palace, enclosure.
Llan	church, enclosure.
Tre tref	village.

Examples are: Ballymena (middle fort), Caermarthen (fort on the seashore), Llanelly (church of St Elain), Lismore (large enclosure).

ROMAN.—Most of the places with traces of Roman origin are those with variations of the word "castra" (a camp) in their name—Lancaster, Colchester, Gloucester, Exeter, etc.

ANGLO-SAXON—

Borough, burgh, bury	fortified place.
Chep, chipping	market place.
Feld, field	plain, field.
Fold	enclosure.
Ham	home, residence.

Lea, ley	pasture.
Minster	monastery.
Mot, moot	meeting place.
Ing	dwelling, a field.
Set	seat, settlement.
Stow	meeting place.
Thorpe	assembly.
Ton, tun	enclosure, village.
Wich, wick	place, farm.
Worth	home.

Examples of some of these descriptions in place-names are: Chipping Norton (market of the north settlement), Oakham (dwelling amid the oaks), Axminster (monastery on the river Axe), Langthorpe (long village), Chiswick (farm making cheeses).

DANISH AND SCANDINAVIAN—

By	farm, village.
Garth	enclosed place.
Kirk	church.
Skip	sheep.
Soke	where a court was held.
Thwaite	cleared place.
Toft	field.

These are found in such names as: Danby (Dane's dwelling), Applegarth (orchard), Kirkdale (church in the valley), Skipton (sheep town—market), Birkthwaite (clearing amid the birches), Lowestoft (lover's field).

NORMAN.—The Normans were responsible for altering many of the earlier place-names in the process of making recordings and inventories of settlement in Britain. They also introduced the family names of the great land-holders of Norman origin into the place-names of the countryside—de Say, de Mohun, Neville, Courtenai, etc.

We now have several different sources of information about the region we are studying, but there are still other sources which may prove valuable. These are impossible to define exactly, for they differ with the region, but may go under the heading of "clues to land-use". It is, for instance, reasonable to deduce that a lowland is a particularly good dairy farming area if, in addition to the maze of water courses, and references to marshes and meads, the scattered farms and network of small roads, we observe that along the railway line which serves the market towns are numerous Halts spaced out a few miles apart. Again, in an area where orchards are marked by symbols, it may be easy to deduce why the map shows long lines of trees bordering the small-holdings—and to recognise these sheltering strips on other maps where the symbols may not be so helpful. None of these observations may be conclusive by themselves but by observing every possible relevant feature we can build up a great deal of evidence to support our ultimate conclusions about the way in which the land has been and is being used.

CHAPTER XIII

STUDY OF SELECTED ORDNANCE MAPS

1. GENERAL DESCRIPTION—LOCAL STUDY

We have suggested already that one of the best ways to study an Ordnance map and its detail is to classify some of the more important features by means of separate tracings of such matters as (1) contours; (2) streams, canals, and lakes; (3) roads and railways; (4) village and town sites in relation to the habitations. The most profitable and really the most educational way of studying Ordnance maps is to use them in conjunction with practical work on some district known to you. It can be your home district or some region to which you have access during holiday. By practical work is meant fairly detailed examination of the region with a view to systematic geographical description. Such a description might deal with the physical features and soils in relation to human activity and settlement.

In this examination try to apply the physical geography you have learned concerning earth sculpture, particularly in connection with the work of streams. If you have sufficient topographical knowledge of the district to visualise it roughly from the map, a preparatory exercise is to examine the map in all its bearings by means of your tracings. The contours will suggest the land forms, and from these you can try to identify broad physical regions, such as a chalk or limestone plateau, a river valley, or the complete stream basin, an alluvial plain, or perhaps a lowland marsh covered with glacial drift. It is well to make rough notes under various headings, *e.g.* "physical features", "suggested physical regions". Later these can be revised or amplified as your practical study of the country proceeds.

Failing a complete personal survey, the next best thing is access to photographs of typical views. Gradually you will be able to expand your tracings and to build up a set of specialised maps, *e.g.* (1) of the physical features analysed to show physical regions; (2) of communications in

conjunction with contours and general physical features; (3) of the habitations and distribution of population in relation to water supply, fertile soil, mineral deposits, etc.

2. PRACTICE IN INTERPRETING CONTOURS AND CONVENTIONAL SIGNS

It will now be helpful to undertake some preliminary exercises based on the portions of Ordnance maps included in this book.

Take a piece of tracing paper about the size of a page of this book, and on it draw a frame corresponding with that of the map studied. Superimpose on the map, and, guided by the contours, write in the appropriate positions the names of various features. The following plan is recommended.

Pick out the highest contour and examine the others in relation to it. This will enable you to identify forms such as a plateau, ridge, hill, peak, or knoll. Next consider the slope, the close contours which indicate a steep slope, and the more widely spaced ones which show a gentler slope. On the tracing paper use appropriate adjectives to describe the features noted. Thus, you may identify a *ridge*, long, narrow (or broad), steep-sided (or with gentle slope); a *plateau*, broad (or narrow), relatively flat (or undulating), steep-sided or otherwise, much (or little) dissected by streams. In connection with peaks look for the sign for a trigonometrical station or a spot height. When dealing with ridges, plateaux, etc., note features associated with them, such as the brow or crest, crest-line or ridge-line, spur, re-entrant, col or saddle, cirque or corrie, or perhaps an escarpment.

So far you have considered the higher land. Now study the *valleys* and *plains*, with their drainage features. In a mountainous region with many close contours and sometimes in a region of uniform relief it is not easy at first sight to pick out the valleys. It may be desirable to use a fresh sheet of tracing paper for the valleys and streams. Trace the streams and other water features with pencil. Then mark and describe the valleys. Suitable adjectives may be used for the valleys to denote their geological age or character, *e.g.* young, adolescent, mature, senile; torrential, narrow and deep (or gorge-like), hanging, stepped, broad, shallow, and flat. Look for the flood plain in broad, flat valleys, and identify features associated with such plains, *e.g.* meanders, ox-bow lakes, embanked streams, straight artificial water courses and drainage channels, marshes, and deltaic flats where a stream enters a lake.

Draw cross-sections and longitudinal profiles of valleys (see p. 119). Such profiles, as well as those of roads, assist the formation of a three-dimension mental picture of the region. Steep-sided cross-sections of uniform width near the floor and top of the valley indicate former glaciation, and breaks or steps in the longitudinal profile suggest rapids or waterfalls. Trace the approximate limits of stream basins and the general direction of the water-parting separating them. It should now be possible to say whether the rocks are impervious, causing rapid run-off, or whether they are pervious, so that surface water is scarce and streams occur only in the lower parts of the valleys.

Next study the *habitations*. On a separate piece of tracing paper mark the sites of towns, villages, and single dispersed habitations such as farms on chalk or limestone uplands. This will assist the formation of a mental picture of the distribution of population. It should be examined in relation to the contours and streams, and a little practice will show how these have influenced the choice of settlement sites. Note how *communications* link up settlements, and carefully distinguish between the various types of road, which may explain, or be a consequence of, the distribution of population. Where the physical features are unfavourable to settlement it is unusual to find first-class roads, but where population is concentrated, as in mining or fertile agricultural regions, there is usually a network of good roads.

Apply the foregoing methods to each of the maps in this book in turn, and to other Ordnance maps. Such practice may be termed the alphabet of map reading, and can be followed by more constructive composition describing the country represented by the map. Begin with a simple examination somewhat as follows, using the Cheddar map.

Preliminary Inspection—*The Cheddar Map* (opposite p. 138).—Note (1) closeness of contours on the top and right-hand side of the map, identifying ridge, plateau, escarpment, spur, re-entrant, gorge, dry valley, cliff, caverns, and the highest triangulation stations or spot heights for comparison with the low-lying river valley; (2) absence of contours in most of the valley, its drainage features, distinguishing between natural and artificial water courses, road and railway bridges over water courses; (3) contours in bottom left-hand corner of map and difficulty of obtaining from them any indication of relief features.

It is now possible to divide the area represented by the map into three well-defined physical regions indicated by (1), (2), (3), in the preceding paragraph, namely, scarped upland, alluvial flood-plain, and undulating lowland. In each of these divisions identify the habitations, means of communication, and other aspects of human geography, especially possible methods of land utilisation, noting references to "moor", "wood", "rough pasture", "quarry", etc. In examining the railway, note the occurrence of cuttings, embankments, and tunnels.

DESCRIPTION.—(Pages 147-9 give detailed notes on the Cheddar map.)

Take each of the physical regions noted in the preliminary inspection, and, assuming that the top of the map is north, locate them. Give the direction of the upland, and especially of its escarpment, noting minor features which cause a break in the continuity of the latter. The preliminary inspection will have prepared you for this, and use should be made of suitable adjectives. The upland, which is part of the Mendips, is essentially a steep-sided, smooth-topped plateau, to some extent cut up by valleys, which are dry. This absence of surface water, and the fact that the map definitely refers to caverns, suggests limestone structure. Consider the distribution of habitations, noting how villages cluster at the foot of the escarpment where conditions favour spring formation, and contrast with the bare uplands with their few scattered farms; but observe the woods on the upper slopes and the several indications of the type of natural vegetation. Connect the main roads with the valleys and the minor roads with the plateau. "Steep-sided and winding" well describes the valley of which the gorge is a part and which takes the main through-route.

Describe the valley of the Yeo as an alluvial flood-plain, and note the character of the winding river and the artificial drainage channels. Refer to necessity for road and railway bridges, embankments, etc. The railway can be described with reference to both the Yeo valley, the scarp border, and the upland. The almost entire absence of habitations in the actual river valley should be noticed, and the land-use in the valley, shown by the small roads and by the drainage, should be commented on.

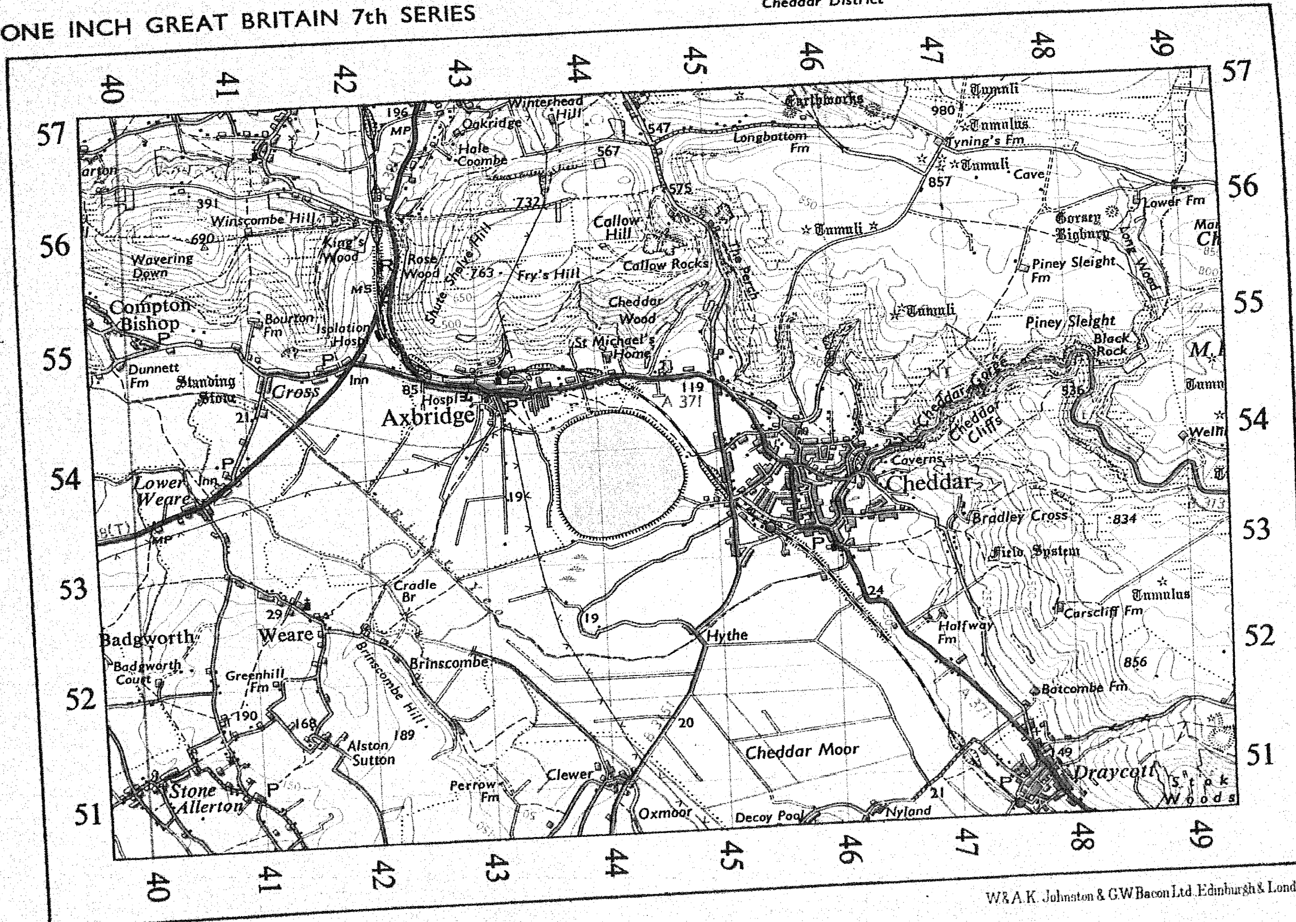
3. THE ENGLISH LAKE DISTRICT

The large 1-in. Tourist Edition sheet of the Ordnance map of the Lake District is recommended for study. It depicts a definite natural region,

ONE INCH GREAT BRITAIN 7th SERIES

Cheddar District

Part of Sheet 165



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and is large enough for parts of it to form the basis of several exercises given on pp. 153-4. The relief is very graphically shown.

The main interest in the English Lake District centres round the relief and the system of drainage. The relief furnishes examples of many different physical features, and from the 1-in. Ordnance map it is possible to obtain much varied practice in the interpretation of contours.

The drainage is of the type known as superimposed drainage, although we cannot tell this directly from the 1-in. map. Superimposed drainage is apparently independent of the present rock structure. Originally the courses of the rivers were determined by some uplift of the surface and were related to the rock structure as it then was. In course of time the streams cut their valleys down into the older rocks, and much of the surface of the younger rocks was worn away by erosion. The original direction of the valleys was maintained, though the rocks originally determining this direction have disappeared.

In the Lake District the older rocks which form the central part of the region are surrounded by newer rocks, which once covered the whole region and formed a kind of dome. The centre of the dome was somewhere near what is now the peak known as Helvellyn, and streams flowed from the top of the dome in all directions like the spokes of a wheel. The newer rocks have been worn away by erosion, exposing the older rocks which had been folded in a direction roughly from south-west to north-east. This line of folds eastward from Scafel to-day serves as a short watershed, but the arrangement of the valleys is definitely radial. Drainage, as from Windermere and Coniston Water, flows south into Morecambe Bay; from Wast Water, Bassenthwaite, and other lakes, south-west and west into the Irish Sea; from Ullswater and smaller lakes eastward or north-eastward into the Eden (see Fig. 95).

In many of the valleys are long, ribbon-shaped lakes fed by the upper courses of streams and drained by the lower courses in the directions noted above. The upper parts of the valleys are generally cut down into the older rocks, and in such parts there is apparently little relation between the rock structure and the direction of the valleys. The lower courses of the streams are on the newer rocks which formed the lower part of the original dome, and their connection with the original slope of the dome is apparent.

On the maps facing p. 142 it is easy to trace the valleys by means of contours, and the valleys help to define features of the higher land. From the closeness of the contours it is evident that the valleys are usually steep-sided, and this is particularly noticeable along the sides of most of the lakes. The valleys cut deeply into the remains of the dome, and thus the drainage may be termed incised. It seems to cut up the surface into blocks of plateaux, from which rise wild peaks, such as Helvellyn, Skiddaw, Scafell. The wildest scenery is where the older volcanic rocks predominate, especially round Wast Water to the west of the dome. In the south, hard rocks known as grits and shales occur, and the contours there show smoother outlines in the district of the low fells, contrasting with the high fells round Helvellyn. There is wooded and park-like scenery round Lake Windermere. On the northern part of the eastern flanks of the dome the less rugged country is mainly limestone moorland, devoted to sheep pasture. The southern part is what is known as karst, with poor limestone soil, little surface drainage, but some underground stream channels and caves.

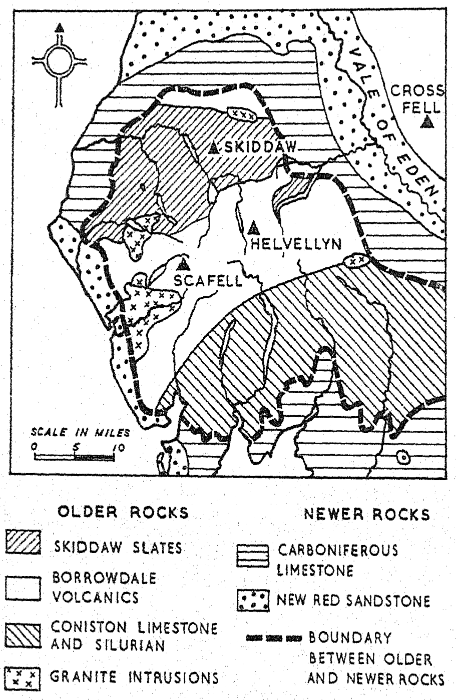


Fig. 95. A Geological Map of the Lake District.

Examination of the map shows that the English lakes are long and narrow, and often almost straight. They are partly in rock basins or hollows in the solid rock, and partly in valleys dammed by drift left by the glaciers which once covered this part of Britain. Their valley sides are very steep, often rising practically sheer from the water. Sometimes the lakes are in

pairs connected by a stream, as Bassenthwaite and Derwentwater, the land between the lakes being like a delta, marshy, and avoided by roads. The stream is extending this delta and is tending to fill up the lake in the lowest part of its course.

Some of the tributary valleys are marked by contours very close together, and are obviously at a higher level than the main valley. They are known as hanging valleys, and the main valley is said to have been overdeepened. Some physical geographers say that such overdeepening occurred when glaciers covered the region, the erosive power of the ice being greater in the wider valley. Those who believe glaciers to have little erosive power think that ice in the main valley protected it from erosion by water, but that streams could develop and cut backwards on the slopes above the ice. Their valleys would be above the level of the main valley and when the glacier disappeared they would remain as hanging valleys. From these valleys, cascades drop into the main stream or into a lake. The famous Fall of Lodore is near Derwentwater. The wild region round Wast Water has many hanging valleys and waterfalls. There are many tarns or small lakes in rock basins, especially east of Thirlmere, and several of them drain into Ullswater or the Eden by means of short streams.

The highest slopes and summits are bare of vegetation. The valleys are generally marked by wooded slopes, and lakeside woods are features of the scenery. Note the closeness of the contours on the heights round Skiddaw, and how they widen out to show the Greta valley. Roads, railway, and villages are in this valley.

Much of what has been said about the Tourist Edition map of the whole Lake District will apply to the $2\frac{1}{2}$-in. **Keswick** map and the 1-in. **Sedbergh** map (facing p. 142).

THE KESWICK MAP.—Points to note in this map are the drainage and the significance of the contours. The scale of the **Keswick** map should be compared with that of the 1-in. Sedbergh map. Particularly note the contours. Draw some topographical sections from each map, especially across the higher ground and consider the slopes thus shown. Compare the distribution of woodland, especially in relation to the contours and aspect. Why does the drainage pattern in the Keswick map appear relatively simple? What impression do the terms "beck" and "ford" give? Can you suggest reasons for the occurrence of the word "spring"? Suggest

possible forms of land-use, especially in relation to physical features. What do you think a town-planning expert might say in relation to the lay-out of Keswick? Note how the valleys and lowland control the routes, how settlement avoids the high land as well as the immediate neighbourhood of streams in the valleys. The nodality of Keswick is obvious, several routes meeting at this site.

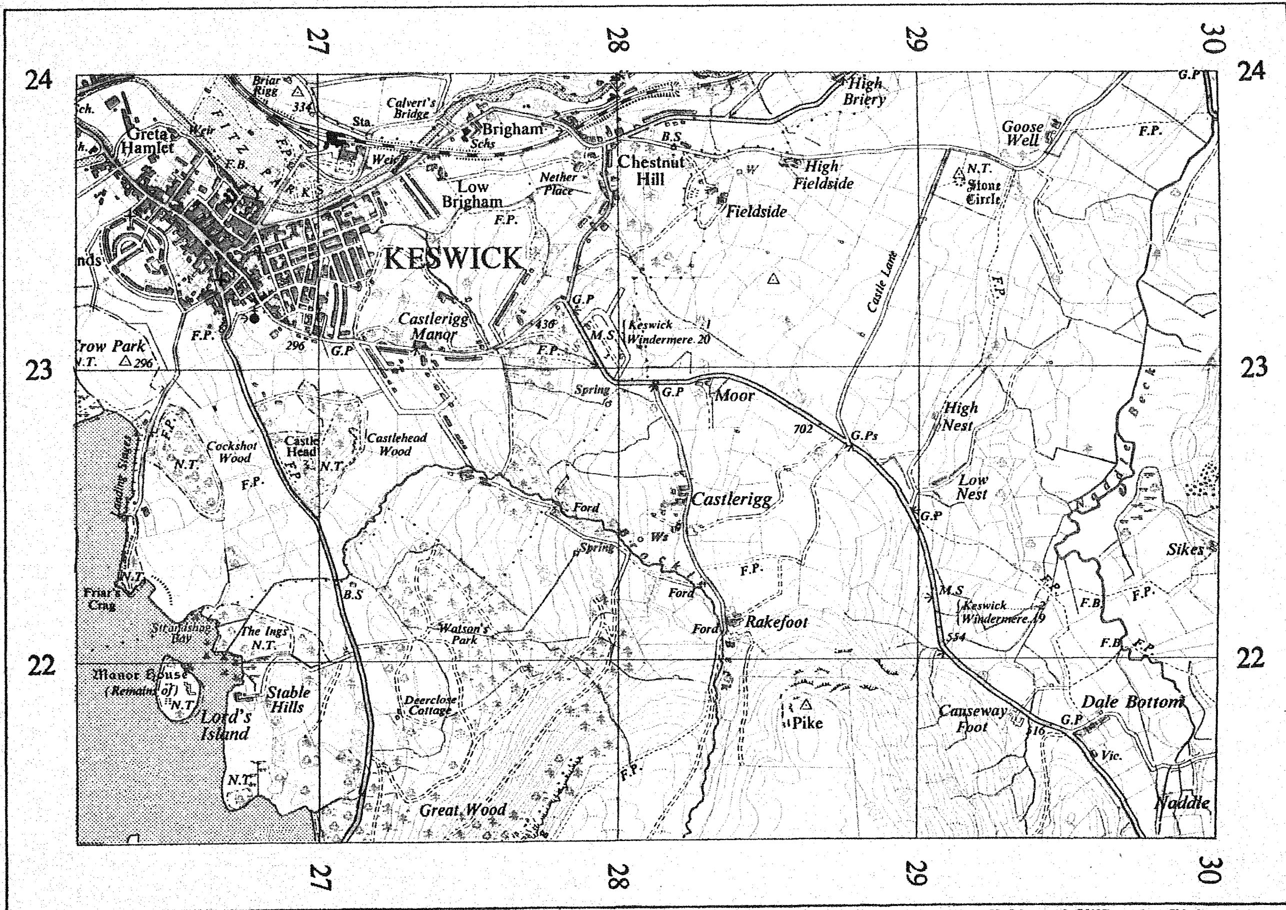
The scenery of the Lake District attracts many tourists. Towns which are by no means large, and sparsely distributed villages, have adapted themselves to cater for these tourists. One of the larger centres is Keswick, on the edge of the lowland between Lakes Derwentwater and Bassenthwaite. Besides being a tourist centre, its nodal position enables it to act as a market for a sparsely populated sheep-rearing and dairying region.

THE SEDBERGH MAP.—An important point in the Sedbergh map is the position of Sedbergh, at a point where five separate routeways converge. The contours guide us in tracing the valleys, which on the whole, are wider than those in the Lake District. They contain larger streams, with more developed flood-plains, across which the streams meander. On the whole, settlement avoids the immediate neighbourhood of the streams, seeking the drier ground on the lower slopes of the upland. Except for Sedbergh, hamlets and isolated dwellings predominate. This is explained by the physical geography, which shows that mountain and moorland are characteristic of the region.

Between the Lune and Rawthey valleys is a stretch of wild mountainous region of the Lake District "fells", where the old hard rock predominates and furnishes poor soil. The radial steep-sided, narrow valleys, which contain small "becks" flowing into the Lune and Rawthey, are not suitable for cultivation, and sheep-rearing is the main industry on the lower slopes. There is mixed farming in the main valleys, but, because of the predominating high land, facilities for this are limited.

Examination of contours shows that in the west altitude is less and that slopes are not so steep as in the area described in the last paragraph. Communication is easier here, and roads, both transverse and longitudinal, are plentiful, though they are of minor importance. They mainly serve villages and hamlets in the Lune valley, there being practically no settlement on the higher fells west of this river.

1:25,000 Prov. Edn. Keswick District Part of Sheet 35/22



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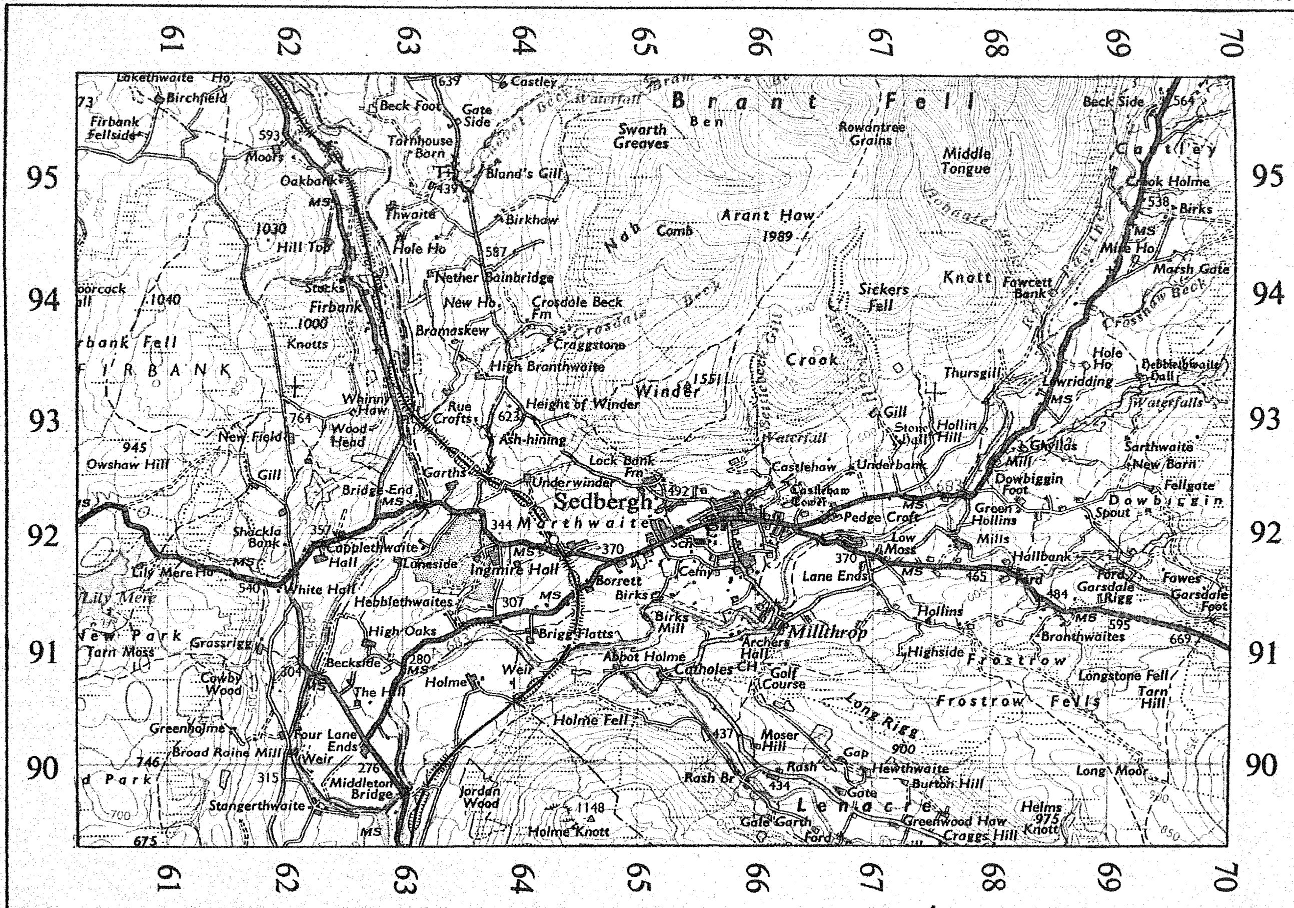

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In the east and south-east of the map the fairly close spacing of the contours and their number denote the steep slopes of tolerably high land. There is a particularly steep slope west of the River Dee, and here there are no transverse roads. The south-east consists of limestone country, shown by the discontinuous lengths of stream indicating underground drainage and by the uniform plateau character of the moorland.

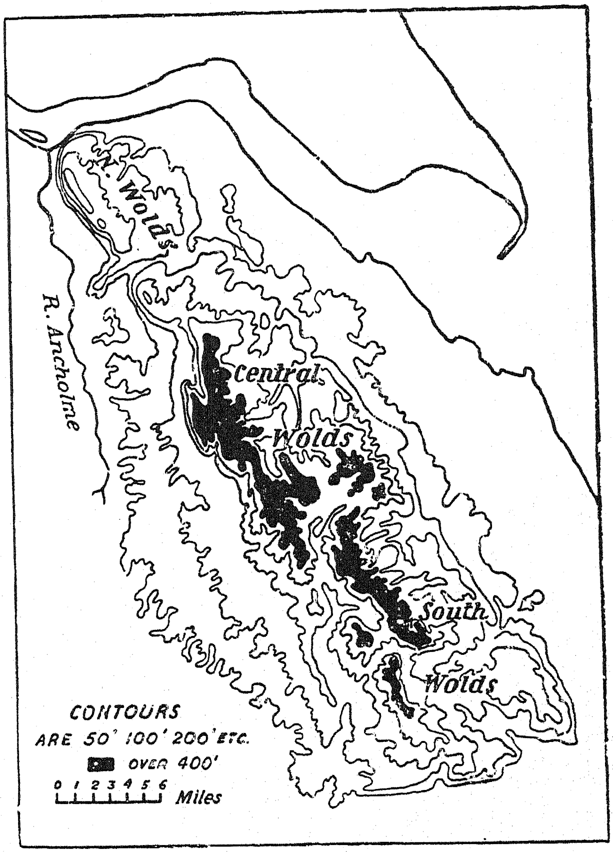

Fig. 96. THE LINCOLNSHIRE WOLDS.

4. THE LINCOLNSHIRE WOLDS: A CHALK UPLAND

The appropriate 1-in. sheets should be used, namely the New Popular or Seventh Edition Sheets 104, 105, 113, and 114, but a small-scale relief map (Fig. 96) is shown opposite.

Study of the Lincolnshire Wolds will give examples of some of the main features associated with chalk uplands. A tracing of the contours of the Wolds shows that the whole constitutes a belt of upland stretching from south-east to north-west, and continued across the Humber as the Yorkshire Wolds. In the west, the contours are close together, and the development

of an escarpment is very clearly shown. Towards the east of the Wolds, the contours are much wider apart, and thus we see that there is a gentle slope in the direction of the lowland marsh which skirts the North Sea.

The Wolds may be divided into three sub-regions, namely, the North, Central, and South Wolds, and this division can be followed if we examine the contours fairly closely. The North Wolds have few streams, and along their western edge the escarpment is lower and more regular than in the other two regions. In the Central Wolds there are more streams, and thus there is a more clearly-defined valley system, especially on the gentler eastern slope. The escarpment is highest and best developed in the Central Wolds, where it is much fretted by the headwaters of small streams which flow west to two larger streams, the Ancholme and Langworth, which are tributary to the Humber and Witham respectively. In the South Wolds the scarp gradually ceases to be a prominent feature, but there are several streams flowing respectively to the Witham and the North Sea. Consideration of the streams and their influence upon village sites affords sufficient contrast to justify threefold division, though each division has distinct characteristics in relation to the escarpment. The North and Central Wolds are separated by a transverse east-to-west depression which is utilised by the railways.

If the valleys could be filled by the material which has been eroded in their formation, the Wolds would be a plateau, and the plateau character of the relief is evident in those parts where there are few or no valleys. The Wolds as a whole can be defined as a dissected plateau of relatively low elevation.

Now consider the streams. With the exception of the Bain, which flows to the Witham, the westward-flowing streams have little influence on the Wold topography, as they are merely the headwaters of streams which originate from springs along the Wold escarpment, where chalk rests on impermeable clay and supplies spring water which cannot make way through the clay. This water fell as rain and soaked downwards through the chalk as through a sponge. It oozes out as springs where the chalk touches the clay, as it cannot make progress through the impervious clay.

There are many villages along the escarpment. If a tracing of the village sites be made, it will be seen that there is a well-developed line of them following the direction of the scarp. They are sometimes called spring-line villages because their sites were largely due to the presence of springs

at the base of the scarp. The scarp is not sufficiently steep to interfere with communications. Make a tracing of the roads and notice that there are many which are transverse routes linking up the eastern valleys and the bordering marshland with the Clay Vale west of the Wolds. The transverse roads generally take advantage of stream valleys, but there are important roads along the length of the ridge and plateau. Contrast such distribution of relatively easy routes with communications in the mountainous regions of the Scottish Highlands, where road construction has been very difficult and is absolutely dependent on the valleys.

Wold villages, apart from those along the scarp-base, are generally in the valleys of streams flowing to the North Sea or tributary to the Witham. Away from the valleys, there are practically no villages, though isolated farmsteads, known locally as "tops" and featured thus on the map, are found here and there on the streamless higher land of the ridge. The problem of water supply is here solved by sinking wells, and the water is often raised by wind-pumps, the symbol of which you will notice.

Practically all North Wold villages are in the west, near the sub-scarp springs, because no streams flow east from this part of the Wolds. If a tracing of the streams and valleys be made, it will be seen why the villages of the Central and South Wolds are more widely distributed. The blanks on a village-site tracing generally fit into the contours which enclose and mark the higher levels of the region.

There are no towns actually on the Wolds, though there are a few small market towns on the borders. This shows that the Wold is essentially a farming region, and that the bordering market towns are collecting centres for the farm produce. The villages are small, and this is explained by the fact that Wold farms are large, because the poor soil does not favour the intensive cultivation associated with smaller holdings. Soil of chalk and limestone regions is always poor, and some of the Wold is mantled by clay and sand left by the old-time ice-sheet. After the Industrial Revolution much was done to improve the soil of this region, which was previously largely given over to poor sheep pasture and rabbit warrens.

5. THE BANCHORY DISTRICT OF THE DEE VALLEY

This map comprises part of the middle basin of the Aberdeenshire River Dee. The Dee valley on the whole lies upon crystalline schists flanked on

both sides by large granite masses. The contours show the rounded character of hard rock surface scoured by heavy glaciation.

The map shows part of the main valley of the Dee, which is marked by incised meanders cut in the hard schists. This comparatively narrow valley is a contrast to the relatively wider valley of the tributary, the Water of Feugh, above Heugh-head. The Feugh valley is here along the boundary of granite to the south and schists to the north and is much wider. The meanders wander about more, and are connected with a network of minor drainage channels. Note the character of other valleys, *e.g.* those of the little burns (streams) in the south-east of the map are hanging valleys: they are above the level of the main valley, and produce small waterfalls where their streams descend to the lower land.

There are river terraces in the Feugh valley, showing that the stream has sometime flowed at a higher level. They are flat alluvial tracts above the present level of the stream, and out of reach of the highest flood level. They indicate that the river has deepened its bed since they were formed.

There are also deposits of glacial drift left by the ice-sheet which once covered this region. Eskers or gravel ridges occur, but these are too low to be shown by the ordinary contour lines. The fact that this valley has been glaciated is shown by the U-shaped cross-section. The meandering stream denotes that its slope is slight. There is very little vertical corrasion, but in places there may be some lateral corrasion of the banks, which will be balanced by deposition elsewhere. Thus shifting of the channel results, and the drainage is indecisive. This indecision is less marked below Heugh-head, where the rock is probably harder and the slope steeper.

The poor soil and the altitude of the uplands of crystalline rock explain the lack of settlement there. Note the forest: consider whether the trees are coniferous, deciduous, or mixed woodland, and account for the prevalence of one particular type.

The contours show a good example of a tabular granite mountain south of the Dee, and marked by the re-entrant valleys of small tributary streams. Re-entrants are also well shown in tabular mountains south of the Feugh, and illustrate the steep-sided narrow valleys of immature drainage. Such torrential valleys are destitute of human settlement.

Note also the general absence of villages in the valley of the Feugh: the meandering stream and the likelihood of flooding explain this. An

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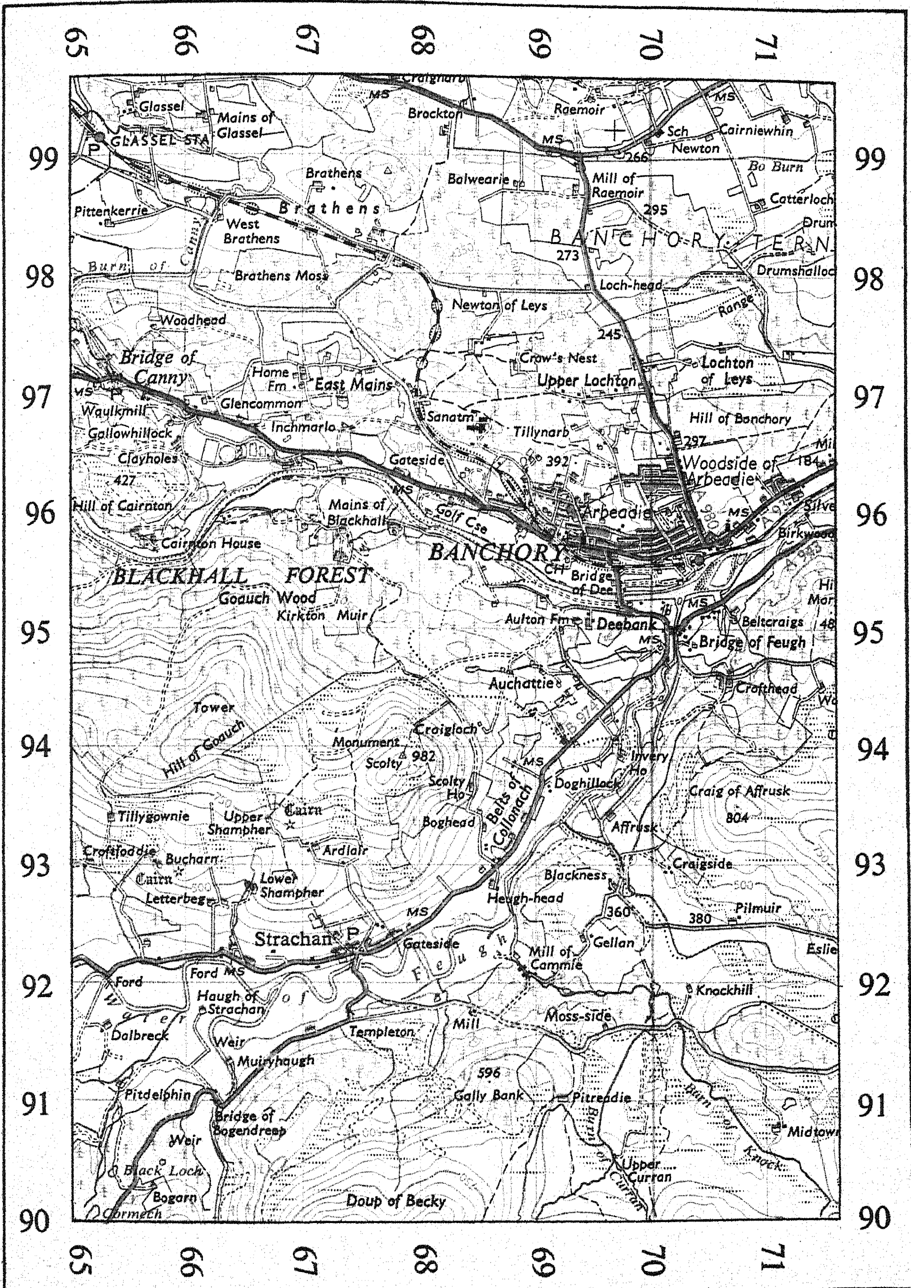
Banchory District

Part of Sheet 40



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exception is the village of Strachan, where the slope of the higher ground approaches the stream.

Several roads converge on Banchory, which was an active market centre in the days when rural fairs were more important than at present. Both the Dee and the Feugh are bridged near Banchory, these bridges emphasising the nodality of this confluence township. Banchory is built on a southward-facing slope and protected from cold northerly winds by the adjacent hills: thus, it has developed into a health resort of some note. Banchory's situation on a southward-facing slope is typical of Deeside villages. The neighbouring heights are well wooded, and the forests furnish material for timber industries. The region is mainly a farming one, the chief crop being oats. Try to explain this by climate and soil. Both sheep and cattle are reared and root crops grown. Suggest which animals are more likely to be pastured on the lower hill slopes and which on the meadows of the Feugh flood-plain. Such points cannot be confirmed directly from the map, but are suggested by it.

Note such names as weir, ford, bridge, mill, and associate them with the streams. Note, too, how the roads and the railway line follow the valleys and the better drained lower land, but avoid the actual stream-side. Explain this, and consider why they do not follow the ridgeway or climb the slopes of the higher land.

6. THE CHEDDAR REGION OF THE MENDIPS

This map (facing p. 138) in the north and east shows (1) part of the Mendip Hills, flanked on the western side by a portion (2) of the Axe basin, and (3) of the higher land of the Somerset plain.

The Mendips are a steep-sided smooth-topped plateau with north-west to south-east trend, and consist mainly of the porous carboniferous limestone, the lower ground bordering them being fertile red sandstone and marls. The Mendips have all the typical features of a limestone region, such as caverns, underground streams, swallow holes into which surface streams disappear and then reappear after an underground course, steep-sided gorges, and scarped slopes. The Cheddar caverns, cliffs, and gorge shown in the map are famous. Note how close the contours are in the gorge, along which a road winds.

The Cheddar Gorge, more than 400 ft deep, has been cut in carboniferous limestone. On the south side, the cliff is almost vertical, but in the north the slope is gentler and sometimes coincides with the dip of the limestone, that is, the slope at which the rocks are inclined from the horizontal. Throughout most of its length, the gorge is dry, but near the lower end a stream flows out of the rock. It is suggested[1] that the gorge is mainly due to underground water, which, by enlarging fissures in the limestone and by the solvent action of carbon dioxide, formed a cave, the roof of which fell in.

In a limestone region like the Mendips, the water circulation is mainly underground. This is because (1) a highly developed system of joints is found in limestone rocks, (2) calcium carbonate is very soluble in water (originally rainwater) containing carbon dioxide. The result is that joint-fissures develop on a large scale and assist the formation of caverns, like the well-known Mendip caves.

The absence of surface water has a peculiar effect on the topography of limestone regions, because when there is a minimum of surface erosion, the limestone forms tabular hills or massive plateaux, often bounded by a steep escarpment like that of the Mendips. Such plateaux have thin soil, and thus possess poor agricultural value.

Dry valleys are a feature of the Mendips, as of other limestone districts. Their method of origin is, however, still a matter for disagreement, even among the experts. Three suggestions are (1) that they were formed during a period of exceptionally heavy rainfall, during, or just after, the Ice Age, when, either (2) the rocks and soil were frozen so that it was impossible for water to sink into the ground and surface drainage of glacial torrents formed the valleys, or (3) a wetter climate or higher sea level led to the raising of the water-table[2] at this time. The valleys could then be formed as normal river valleys which were abandoned when the water-table was subsequently lowered and springs could no longer rise in them.

The River Yeo, a tributary of the Axe, which drains into the Bristol Channel, rises from a spring in the scarp near Cheddar, but the scarp is singularly destitute of stream headwaters, a great contrast to the chalk scarp of the Lincolnshire Wolds. The Mendip scarp, however, is considerably fretted by streamless re-entrants known as combes. The Yeo, like its

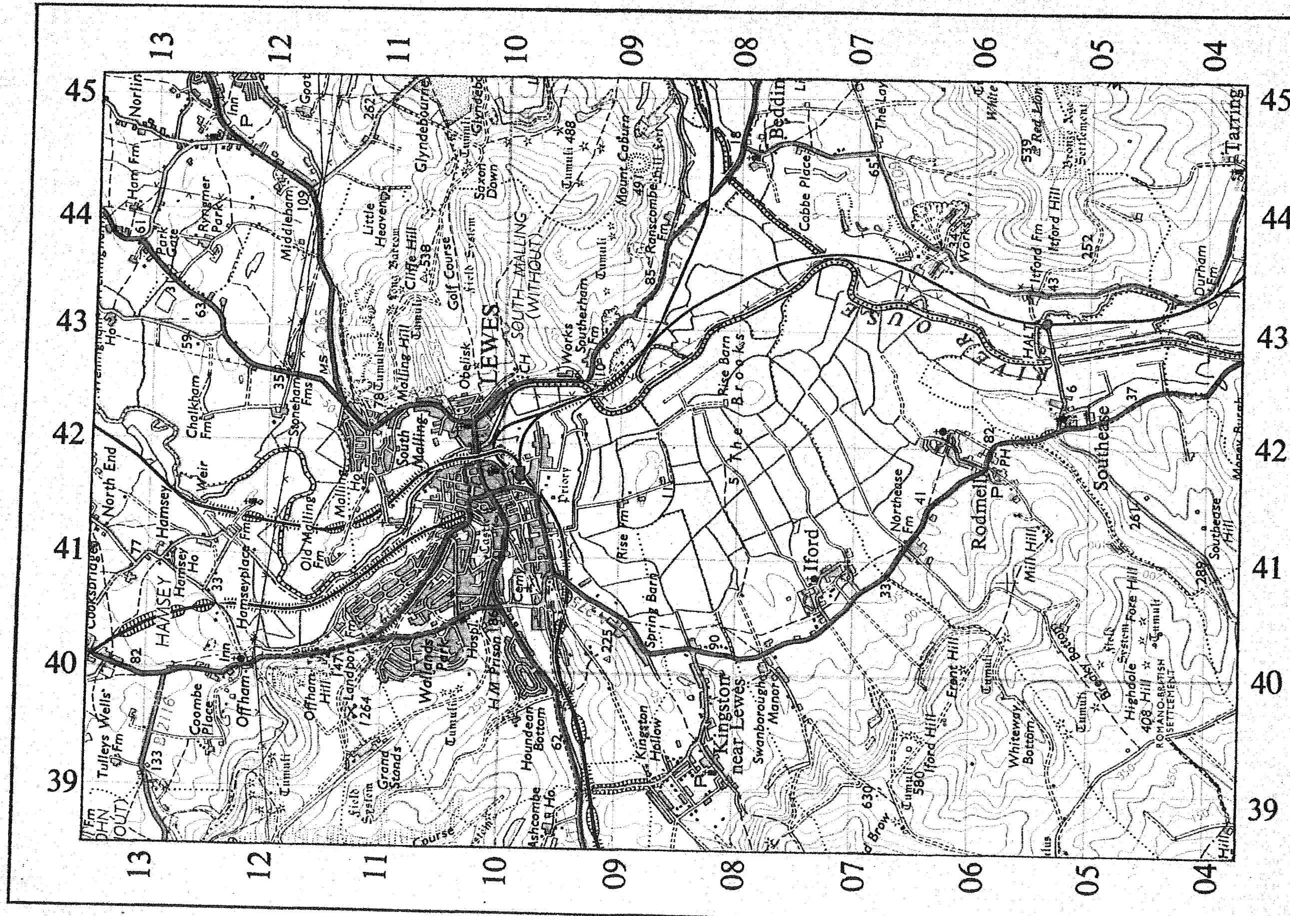
[1] Professor S. H. Reynolds.

[2] "Water-table" indicates the upper surface of water which saturates pervious rocks such as limestone.

ONE INCH GREAT BRITAIN 7th SERIES

Lewes District

Part of Sheet 183



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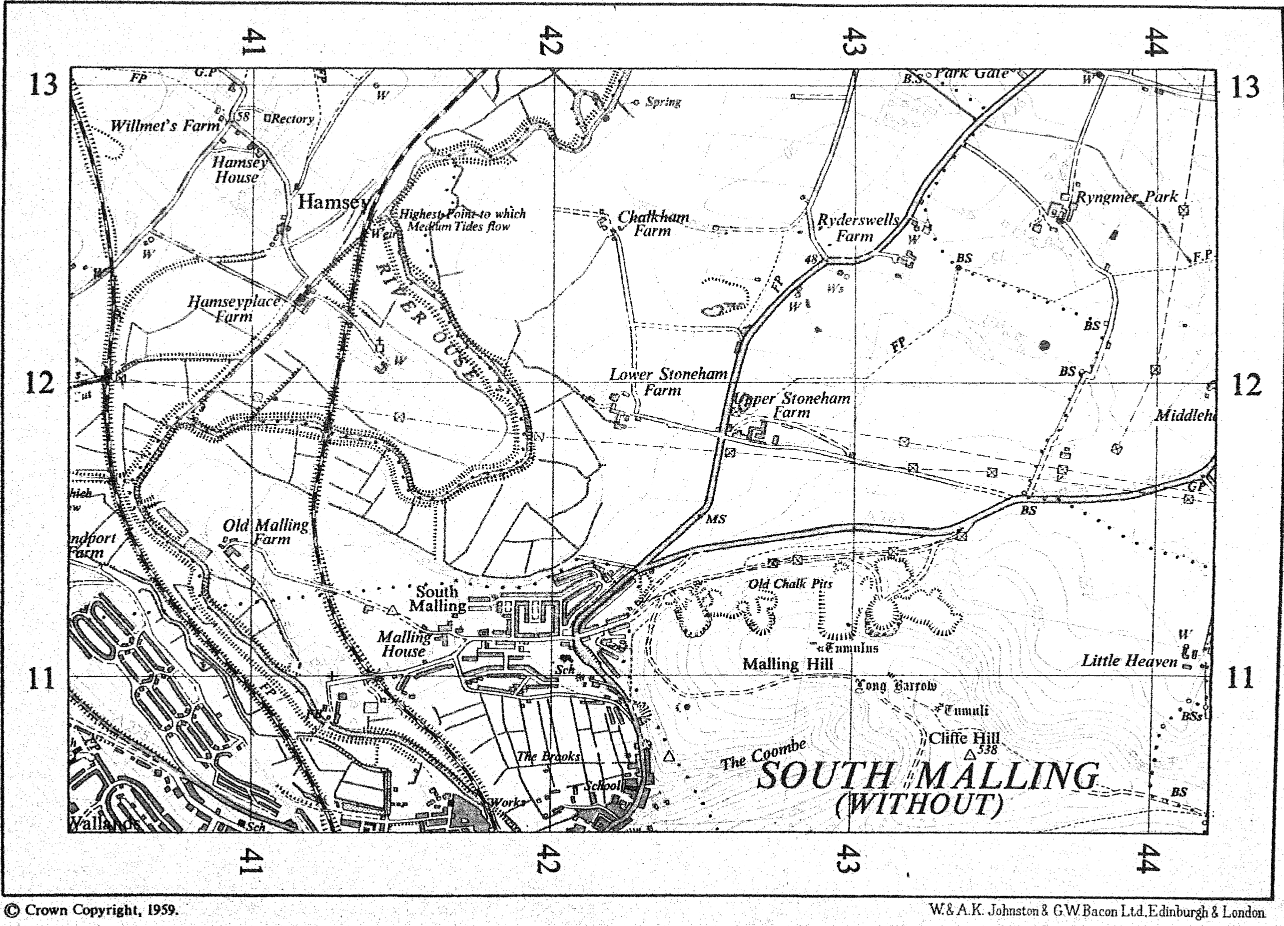
1: 25,000 Prov. Edn. *South Malling District* Part of Sheet TQ 41



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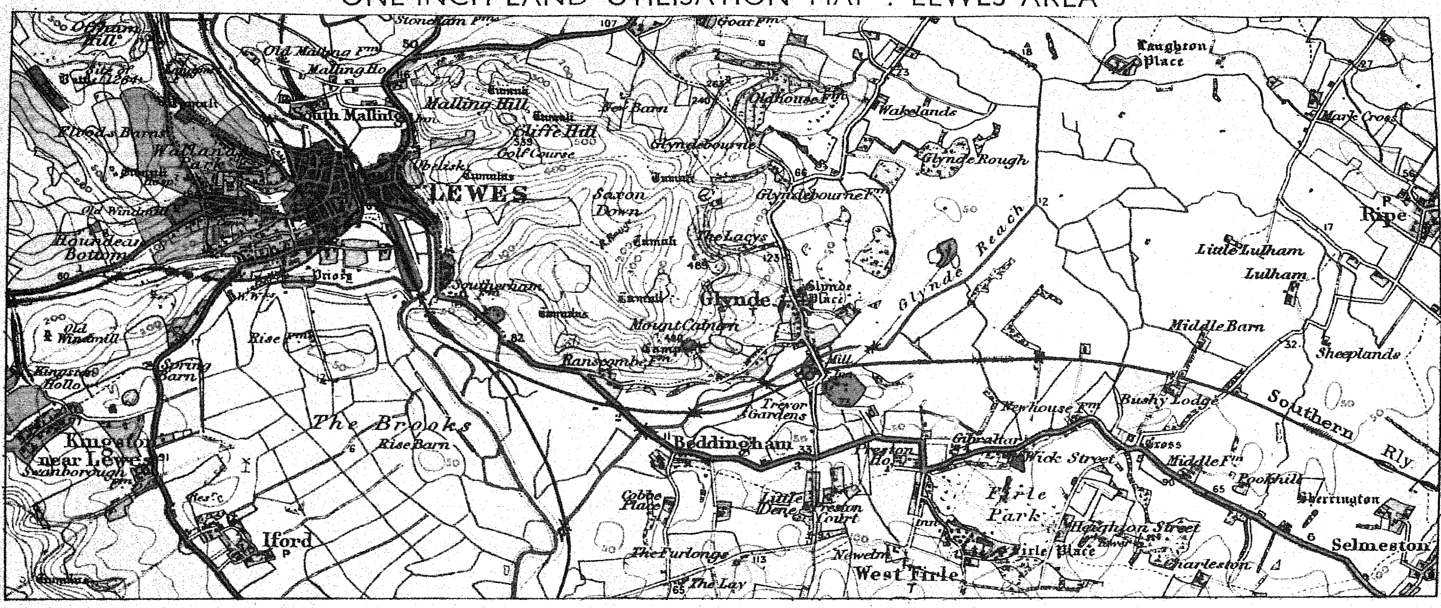
ONE-INCH LAND UTILISATION MAP : LEWES AREA



Forest and Woodland		Arable land including Fallow and Rotation Grass - - -		Gardens, Allotments and Orchards	
Meadowland and Permanent Grass		Heathland, Moorland, Commons and Rough Pasture - - -		Land agriculturally unproductive including Buildings, Yards, Cemeteries, etc.	

Main roads shown in red ; water areas in blue.

In addition to the ordinary Ordnance Survey symbols the map shows parish boundaries thus : ....

Scale of One Inch to One Statute Mile = $\frac{1}{63360}$

8 7 6 5 4 3 2 1 0 — 1 — 2 — 3 — 4 — 5 *Miles*

1000 — *0* — *1000* — *2000* — *3000* — *4000* — *5000* — *6000* — *7000* — *8000* — *9000 Yards*

Reproduced from the Land Utilisation map by permission of the Director, Land Utilisation Survey of Britain, London, W.C.2 Outline, water and contours reproduced from the Ordnance Survey map with the sanction of the Controller of H.M. Stationery Office. Printed by W. & A. K. Johnston & G. W. Bacon Ltd., Edinburgh and London.

parent stream, has in parts been canalised, a fact shown by straight reaches. The straight drainage channels are characteristic of a marshy lowland. The frequent occurrence of the word "moor" here, and the absence of settlement, emphasises the low economic value of the river flood-plain.

The higher parts of the Mendips have the flat-topped features of a plateau, intersected by several narrow, streamless valleys, which are utilised by roads. The site of an old Roman road is on the higher ground, following the practice of early times, when roads clung to the dry ridgeways and avoided the marshy, and often wooded, valleys. Villages are absent from the Mendip upland, where, however, there are isolated farms, as in the Lincolnshire Wolds. Lack of water, except from wells, is largely responsible for the absence of village sites on the uplands. Cheddar, Axbridge, and three other fairly large villages lie at the foot of the scarp on the fertile red sandstone, and roads radiate from them northwards through the Mendip valleys as well as along the scarp border. Major roads and railway, like the villages, avoid the river and its flood-plain, but notice the small roads and the drainage channels in the valley.

In the south-west of the map, where the sandstone and marls give higher land and fertile soil, there are several villages connected by longitudinal and transverse roads. These are relatively large villages, often spread out along a road.

This map gives several contrasts in regions and their economic significance. On the whole, it represents a farming district, engaged in dairying, mixed farming, and fruit growing. The chief regions are: (1) the plateau and scarp of the Mendips; (2) the Yeo valley, roughly parallel to the scarp; (3) the low plateau of the south-west.

7. LEWES AND THE DOWNLANDS

Lewes commands the gap cut by the River Ouse through the chalk downlands. East and west of the town, where the chalk hills rise above the lowlands, there is no visible surface water and the valleys are dry. By contrast, in the north there is considerable surface drainage over the lowlands and the river can be seen meandering across the countryside in loops and braids. To the south the waters of Glynde Reach also flow through a gap in the chalk hills to join the Ouse. Here the main valley widens, enclosing a broad silt-covered flood plain. The meandering river shows many signs

of its old age, for the fall from here to its mouth near Newhaven, three miles to the south, is very slight. Ox-bow lakes can be seen alongside the river. The swampy ground to the west of the river has been well drained by a number of man-made channels, features which can also be seen on the 2½-in. map to the north of the town.

The map shows us unmistakable signs of a long period of human occupation. Early settlement is indicated by the many barrows and tumuli and by the Celtic fields on the Downs. A study of the camp on the prominent Mount Caburn shows that it closely follows the contours. It is, in fact, made up of a series of well-sited contoured earthworks, with only one entrance. A study of the modern place-names shows us that, as is usual, many of them are derived from descriptions of the holdings of Saxons or Early English peoples. Lewes itself is from *hlaewe*—the place on the hillside; Malling tells of the land held by Mealla's people; Swanborough has evolved from *Swana-beorg*—the peasants' hill; Offham tells of a "crooked" land holding (referring to the sharp bend of the Ouse); while Rodmell is probably from a descriptive name—Red-mylde, or red soil (mold).

During the feudal period Lewes gained in importance as a strategic town, with its castle dominating the river gap. The names of great families appear in the place-names of the district—Hamsey, on land belonging to the de Seys, while Tarring (once belonging to the people of Teorra) acquired the name of the Neville family. One of the major clashes during the Barons' Revolt is recorded on the present-day map, which shows the site of the battle near Lewes in A.D. 1264.

The map shows that the river is tidal to a point north of the town, and in later times Lewes received much traffic along the Ouse. Recent features of settlement can be seen from the symbols which indicate the location of modern villages, housing, parks, farms, etc. The 2½-in. map shows old chalk pits to the north-east of Lewes, while the modern cement works shown on the 1-in. map (425095 & 437064) tell of a more up-to-date use of the chalk.

The communications are much influenced by relief. Lewes is approached from the south by roads and railway which follow the slightly higher land along the side of the Ouse valley, but lie beneath the downs; and power lines closely follow the path of the railway. To the south-east of Lewes there are road and rail connections through the Glynde Reach gap, while the road and railway from the south-west of the town pass between chalk

hills, along the line of an old Roman road. The routes are concentrated on the main Ouse gap and pass through Lewes to the north. Here modern roads follow ancient tracks along the foot of the chalk, while a network of minor roads spreads out over the lowlands away from the flood-plain.

The land-use map shows the influence of relief and rock types. Stretches of meadowland and grass cover the flood-plain. On the reasonably gentle, cultivable slopes are areas of arable land, even where, south of Lewes, the small humps known as the "Rises" stand out above the grassy plain. Above the lower slopes lie meadowland and rough pasture on the Downs. Notice that the location of the villages with their small-holdings stand out clearly on this type of land-use map.

8. CRITICAL CARTOGRAPHICAL AND GEOGRAPHICAL DESCRIPTION OF A MAP

In examinations, questions are sometimes set dealing with British Ordnance maps or similar foreign maps, especially French, German, and Swiss maps. Examiners may require a critical cartographical description of the map, a general geographical description of the area represented by it, or the description of some particular aspect, such as treatment of the physical or human geography, or parts of these, such as relief or drainage, settlement, or communications.

In a critical cartographical description the map should be described and criticised as a piece of map making, but description of the area represented by the map is not required. It is necessary to consider for what purpose the map is primarily intended, and then to determine how far the methods employed to represent geographical facts have succeeded in giving adequate information in an easily legible form. Suppose you have to give a cartographical description of a topographical map such as one of the Ordnance Survey one-inch series or a foreign map on the scale 1 : 50,000. Firstly, if possible, name the projection used, with a note on its suitability. This would give a lead for reference to representation of latitude and longitude, to sheet-lines and any indication of relationship with neighbouring sheets, the use of a grid and its coordinates in relation to the scale. Next make a very thorough examination of the means used to represent geographical facts, especially the use of graphic and easily read conventional signs and of suitable and legible lettering. By suitable lettering we mean that which

will emphasise some geographical fact in addition to identifying a feature or place, for example, different types and sizes of lettering to show the relative importance or the population in round figures of towns. You must describe and criticise the method of depicting relief, noting the limitations of hill-shading or hachuring, the overcrowding or absence of contours, the use of hypsometric tints, and suitability of colours used. Criticise the use of colours for water features, roads, woodland, and other vegetation, etc. It may be helpful to adopt some standard of comparison, for instance, comparison with another edition of the same scale Ordnance map, or with a similar foreign map. Such comparison should not be overdone, and might be confined to points where the map criticised shows marked inferiority.

In a general geographical description of the area shown on a map, carefully balance the facts of physical and human geography, using the former to explain the latter. It is usually as well to start with a division into broad physical regions, and then work forward to the relief and physical features of each region, noting how these explain the location of settlements and communications.

EXERCISE V

Ordnance Maps (Llanberis)

Study the 7th Series 1-in. O.S. map showing part of the countryside near Llanberis (part of Sheet 107)—the frontispiece.

1. Describe with examples the different methods used here to show the relief. Say why it is necessary in this case to use different methods.

2. Construct a cross-section of the countryside between pt. 1076 (5659) and map ref. 650620. (To avoid an unnecessary number of construction lines choose carefully the vertical interval to be used in plotting.)

3. Describe and account for the nature of the valleys of the Nant Ffrancon (6460-6364) and Afon Dudodyn (6160).

4. Compare the lakes Llyn Padarn (5761), Marchlyn Mawr (6162), and Llyn y Mynydd (6064) in terms of their appearance, location, and the ways in which they have been formed.

5. Give map references to indicate examples of the following physical features: a corrie (without a lake), an arête, a hanging valley.

6. Suggest why Llyn Padarn and Llyn Peris are separated by the tongue of lowland to the east of Llanberis.

7. What evidence is there of the nature of the rocks which form the highland?

8. What features have influenced the pattern of the communications in this area?

9. Describe the forms of land-use (*a*) which are directly indicated on the map, (*b*) which you can infer as probably carried on in this region.

EXERCISE VI

ORDNANCE MAPS (THE LAKE DISTRICT)

The following questions 1 to 20 are based on the Tourist Edition of the Lake District map, which is required, but most of them can be adapted for use with any other Ordnance map.

Suitable maps for study are sheets dealing with—

(*a*) The Pennines, Cotswolds, Chilterns, Downs, Lincoln Edge, Lincolnshire, and Yorkshire Wolds.

(*b*) North Wales, Highland and Southern Uplands of Scotland (especially river valleys of such regions).

(*c*) Cornwall and Devon, especially Dartmoor, Exmoor.

(*d*) Fenland, Vale of Pickering, Weald, Lower Trent Valley, Vale of York.

(*e*) Coasts of Holderness, south-east Suffolk and Essex, Kent and Sussex, Cornwall-Devon, West Scotland, Moray Firth.

A suitable selection can be made from the Index Sheet of the 1-in. Ordnance maps. It is advisable (1) to study carefully examples of maps representing different types of country, and (2) to analyse them on lines suggested by the following questions:

1. Reducing the scale to 5 ml. to the inch, draw sketch-maps showing—
   (*a*) Distribution of woodland, and account for its presence.
   (*b*) Lakes and streams, noting what features in the original are necessarily distorted.
   (*c*) Routes and towns, explaining how far the sites of the towns seem to be influenced by physical features.

2. Adopting a scale of 6 in. to the mile, enlarge portions of the map as follows:
   (*a*) Districts (say about 10 or 12 sq. ml.) immediately around (i) Skiddaw, (ii) Helvellyn, (iii) Scafell, noting what may be deduced from the contours and analysing character of the slopes.
   (*b*) District covered by squares F1, F2, F3 on the grid (Buttermere, etc.), writing brief notes on the physical features.

3. Reducing the scale to 4 ml. to the inch, draw sketch-map showing—
   (*a*) The relief simplified. (*b*) The drainage.

4. Use the above sketch-maps to suggest possible division into physical (or physiographic) regions, justifying such division.

5. In connection with the map required in Question 3 (*a*), explain the method adopted for showing the simplified relief features. Why is it difficult to reduce the map literally in this respect?

6. On a reduced sketch-map (scale 4 ml. to the inch) show the distribution of villages by a small circle and towns by a square.

7. Discuss broadly the general distribution of population shown on this map, and explain clearly why the blanks occur.

8. With the aid of a sketch-map of scale 4 ml. to the inch, explain how far the area is served by (i) first-class, (ii) second- and third-class, roads, and account for the occurrence of these different types of road.

9. Draw sections true to horizontal scale, and with the least possible exaggeration of vertical scale for country indicated by a straight line between the following places:

(*a*) Ambleside and Windermere.
(*b*) Buttermere and Borrowdale.
(*c*) Great Dod (D7) and Barton Fell (D10).

10. Describe character of country shown by the above sections.

11. Draw longitudinal sections of the roads from—

(*a*) Kendal to Bowness-on-Windermere.
(*b*) Kendal the township of Windermere.
(*c*) Coniston to Ambleside.

12. Compare the character of the above roads, giving reasons for any striking differences.

13. Draw sketch-maps of the following lakes on a scale of 6 in. to the mile, and include sufficient contours to show the relief of the lakeside regions:

(*a*) Hawes Water (*b*) Coniston Water.
(*c*) Wast Water. (*d*) Ullswater.
(*e*) Thirlmere. (*f*) Crummock Water with Buttermere.

14. Similarly, draw maps on scale of 3 in. to the mile for—

(*a*) Windermere.
(*b*) Derwentwater with Bassenthwaite.

15. Analyse the maps drawn under Questions 13 and 14 in an endeavour to describe the general features of the various lake basins of the Lake District.

16. Taking Trout Beck flowing into the eastern side of Windermere, draw an enlarged sketch-map on scale of 6 in. to the mile, showing the contours. Then draw about half a dozen cross-sections of the valley, and, using them, discuss the physical character of the valley.

17. Draw, based on this map, contoured sketches on an enlarged scale of 6 in. to the mile to show (i) a hanging valley; (ii) a col; (iii) a re-entrant; (iv) a spur; (v) a scarped slope; (vi) a cirque; (vii) a rounded hill; (viii) portion of dome with radial drainage.

18. Analyse the place names, *e.g.* pike, fell, to illustrate the general character of the physical features.

19. Select from the region (i) a main valley floor; (ii) a lakeside plain or border; (iii) a lofty summit; (iv) a moderately high plateau; and describe the general character of the landscape as seen from your position.

20. Co-ordinate what you have deduced in connection with Question 19 and give a summary account of the landscape associated with the Lake District.

21. For each of the small maps for Keswick (p. 141), Sedbergh (p. 142), Banchory (p. 145), Cheddar (p. 147), apply from the above exercises the following questions: 1, 3, 4, 6, 7, 8. Contrast the physical features and relief of the Banchory and Cheddar maps, briefly noting their probable effect on human occupations.

22. Write a short essay on the usefulness and the limitations of contours for showing relief, illustrating in the latter respect from maps for regions such as the Lake District and the English Fenland.

CHAPTER XIV

DISTRIBUTIONAL MAPS AND THE GRAPHICAL REPRESENTATION OF STATISTICS

1. DISTRIBUTIONAL MAPS

In the development of modern geography, and particularly of the map as a geographer's tool, the sketch map or diagrammatic method was largely used before more elaborate attempts were made to compile distributional maps from actual statistics. Sketch-maps may still be considered as an invaluable aid to a student presenting an account of a region, for although such maps usually have no quantitative basis, either of scale or of data, they provide valuable notebook summaries to counteract the "wooliness" of long verbal descriptions. For more advanced work, however, and for use in published matter, they can be very misleading when applied to distributional purposes.

If the word "wheat" is written across the Canadian Prairie Provinces, it merely means that wheat is grown in certain parts of these provinces, and not necessarily everywhere where the letters W H E A T occur. On a map, to colour a district yellow for wheat, green for tea, may give the idea that the country is uniformly devoted to such crops, which is absurd. There may be lakes, deserts, or stretches of unfavourable soil, or there may be land too high to grow such crops. To write "Slavs" over a region may suggest that the people there are all Slavs, though there may be as many other people as there are Slavs.

Distributional maps based on definite data have considerable geographical and educational value, but even their value is limited. The commonest types are those indicating distribution of stock, crops, and population. During their compilation, it is necessary that certain physical maps should be consulted, for instance, maps showing relief and soil, climatic maps concerning temperature and rainfall.[1] The best distributional maps are but cogs in a wheel, not the wheel itself. The statistical facts conveyed

[1] Many of which are themselves distributional maps of one type or another.

by them may help the geographer to apply his arguments and to trace his ideas of cause and effect, but in themselves they are not geography.

The statistical bases of such maps for England and Wales are usually official returns of the Ministry of Agriculture, of the Board of Trade, or Census Returns.

2. THE DOT METHOD

The dot method may be used for crops or stock or population when absolute, *i.e.* exact as distinct from average, figures are given.

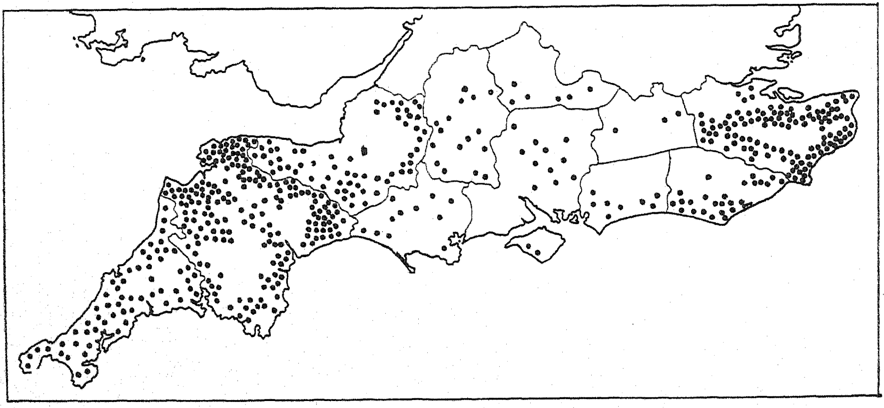


Fig. 97. Distributional Maps—The Dot Method
[showing the distribution of sheep in southern England (each dot represents 5,000 sheep)].

An outline map showing the political divisions such as parishes or counties is needed: this serves as the basis of the distributional map. For guidance in placing the distributional data, a contoured map and a geological or soils map are required when a distributional map showing crops or stock is to be prepared. To assist preparation of a population map, an Ordnance map showing town and village sites is desirable. The most carefully prepared distributional map cannot be other than approximately correct; however, there are degrees of approximation, and it is possible to construct such maps to show actual conditions with reasonable approach to general accuracy if not as regards minute detail.

We will illustrate the method by preparing a map showing the distribution of sheep in English counties south of the Thames. The statistics are Ministry (formerly Board) of Agriculture figures for a single year (1955), which were selected because the published acreage and live stock returns for that year give both the absolute numbers for each county as well as averages per thousand acres. The former will serve to illustrate the dot method; the latter will be used later (see p. 161) for the shading method.

The statistics used are given below in a table which shows not only the number of sheep in the selected counties, but also the units of 5,000 sheep per county.

County	Number of Sheep	Units of 5,000 Sheep
Cornwall	291,876	58
Devon	937,144	187
Somerset	306,647	61
Dorset	51,015	10
Wiltshire	82,539	16
Berkshire	32,579	6
Hampshire, exclusive of Isle of Wight	56,650	11
Isle of Wight	7,637	2
West Sussex	39,552	8
East Sussex	125,664	25
Surrey	15,258	3
Kent	549,903	110

The first step is to decide how many sheep each dot shall represent. If the outline map is merely a tracing from an ordinary atlas map, it is not large, and thus there must not be too many dots to produce a blurred effect. A convenient unit seems to be 5,000 (Fig. 97). There are two or three counties where few dots are required, and where there cannot be much real distribution shown.

Next, in each county pencil lightly the nearest figure indicating units of 5,000 sheep, as shown in the third column of the table above. These figures assist the placing of the dots and can easily be erased if desired. Before placing the dots a map showing the physical features should be consulted.

Certain areas are obviously little suited to sheep, while in others the flocks are very important. We therefore avoid the New Forest in Hampshire

when placing the dots, and regions such as the Weald, the Thames valley, parts of Surrey and Kent near London, are given fewer dots than the rest of their particular county. Such regions contain some sheep, but are more important for market gardening, cattle-rearing, tillage, or as residential areas. By contrast the chalk uplands, especially the South Downs, show heavy sheep density; so does the Romney Marsh district of Kent. The South Down and Romney Marsh breeds from these regions have formed the basis of flocks in New Zealand and other Commonwealth countries.

This broad differentiation of regions favourable or unfavourable to the commodity being mapped is necessary on a county map, but the method, obviously is in no way so reliable as one made from statistics for parishes or groups of parishes. However, it gives a truer picture of actual conditions than regular spacing of dots all over the county. Such regular spacing is more comparable with the shading method, the limitations of which are noted on p. 160. Compare Figs. 98 and 99.

When working on a large-scale map with small units of area, such as parishes, it is obviously easier to avoid assigning a heavy density to areas rendered unsuitable by adverse physical features or poor soils for example, than when working with larger units where a smaller scale is also almost certain to be used. On the small-scale map it is not easy to distinguish between the various geographical factors operating, for even in a small county, variations in soil, climate, and relief will in all probability occur. For instance, in mapping the crops of Norfolk, the Broads must be avoided. In mapping crops for Cumberland, the mountains and lakes must be avoided in the dot distribution method.

The distribution of any "negative areas" should first be studied by reference to good relief, geological, and climate maps. If these are then lightly marked in pencil on the outline map being used, care can be taken to avoid them when plotting. In this way symbols can be concentrated in the most suitable places for the commodity concerned. Care should also be taken where necessary to give a continuous effect across such artificial lines as county or parish boundaries.

Even in favourable areas, however, smaller variations in density occur and it is seldom possible, therefore, to compile anything more than an approximate generalisation by using the dot method unless a very large-scale map is being used.

UNITS FOR THE DOT METHOD.—Care is necessary in selecting a suitable unit to be represented by each dot. There will be fewer cattle than sheep per 1,000 acres, and therefore this must be borne in mind when selecting the unit. For cattle, one dot might represent 25 or 50 according to the scale of the map. For sheep, one dot might represent 100 animals. The dots must not be so numerous and so small as to be read with difficulty. We must avoid a unit which causes the dots to give the effect of a continuous blur, likely on a small-scale map if they indicate too few animals. On the other hand, if they indicate too many, the distribution may become too generalised and of little quantitative value.

The blurred effect is often noticeable in textbook reproductions of a map from official sources, such as year books. The map was prepared on a reasonably large scale, and the dots were quite legible not only on the original but on the officially reproduced copy. Permission may be given for reproduction of the latter in some textbook or journal, possibly on a smaller scale, and then the dots become less legible.

The other extreme sometimes occurs when the dot method is used for world distributional maps. Such maps, possibly drawn on an equal area projection like Mollweide (see p. 249), are necessarily on a small scale. For the sake of legibility, few dots must be used, and thus a very big unit is necessary. If, as is sometimes the case, one dot is made to represent 100,000 sheep, only very generalised distribution is possible, and some small countries where sheep are reared may not find a place on the map. However, such diagrams are not without their uses if they are regarded as indicating the relative importance of sheep-rearing countries. Their practical geographical utility, however, is only small if they are not examined in conjunction with climatic and vegetation maps.

USES OF THE DOT METHOD.—The most common use of the dot map is in illustrating stock, crop, and population distributions from actual (as distinct from average) figures, but the dot method can be used for many more purposes than would be possible with the shading method (see p. 160). In a map of the coalfields, dots can represent the sites of collieries, the size varying according to the number of men employed. The number of men employed underground in the various pits can be gathered from Government figures published in Lists of Mines.

The dot method can also be used to indicate the sites of fairs or of markets in an agricultural region, or, say, co-operative factories in a dairying country such as Denmark. Various sized circles, which are adaptations of the dot method, can be used to denote utilised and available hydro-electric resources in a country like Sweden or Finland. In these cases, where it is obviously necessary to indicate absolute figures, the shading method is not suitable. Some modern atlases use "spheres", drawn to give a three-dimensional impression, whose volumes represent a number—usually a number of people in a city on a population map.

3. THE SHADING METHOD

The shading method may sometimes be useful for crops and stock when average figures per unit area are given. According to this method, distribution is shown by different tints of colour layers or by distinctive methods of black and white shading. Such methods may be found suitable where only average statistics are available, for example, so many cattle or sheep per 1,000 acres, or a percentage area under, say, wheat. The dot method can only be used where actual figures are given, in which case the less accurate shading method should be avoided.

The weakness of the shading method is that distribution appears uniform over the whole area. In the distributional map of a county or large island, no account can be taken of waste, or relatively unimportant, land, such as desert or moorland, where, probably, no crops at all are grown. The shading method gives the impression that, say, wheat is as important in such areas as in the rest of the region.

If the shading method is followed, the basis, as in the case of the dot method, is an outline map of administrative divisions for which statistics are available, *e.g.* counties, parishes, or groups of parishes. Suitable units must be selected, *e.g.* for cattle, say, under 100, 100-25, 125-50, 150-75, 175-200; for sheep, under 100, 100-200, 200-300, 300-400, etc., per 1,000 acres. A key to the shading is constructed as in Fig. 98. If colour is used, it is well as far as possible to select tints of one colour rather than to employ several colours. If provision must be made for many different figures, varying tints of similar colours, such as brown and yellow, might be used, the darkest tint for the highest density; a heavy black tint should,

however, never be used as this gives a false impression of excessively intensive and exclusive distribution.

It is a good plan to pencil lightly the figures in each division. This prevents mistakes, and the figures can be easily erased when the map is finished. Compare the map (Fig. 99) showing sheep distribution for certain counties with that made by the dot method (Fig. 97) for the same counties. It will be particularly noticed that, with the shading method,

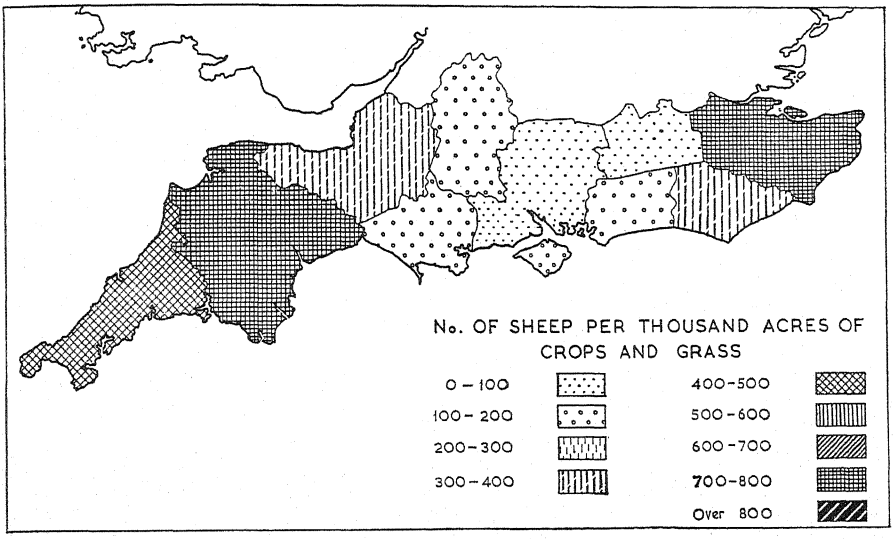


Fig. 98. DISTRIBUTIONAL MAP—THE SHADING METHOD.
To show the distribution of sheep in southern England. (Average for the years 1952-55.)

no differentiation between areas of different densities is possible within the counties.

As in the dot method, the smaller the area units into which the map can be subdivided, the better the map is produced. The sharp division between heavy density of sheep in Kent and relatively light in Surrey (Figs. 98 and 99) does not in fact occur exactly along the county boundary, for example, although such lines nearly always appear on maps made by this method.

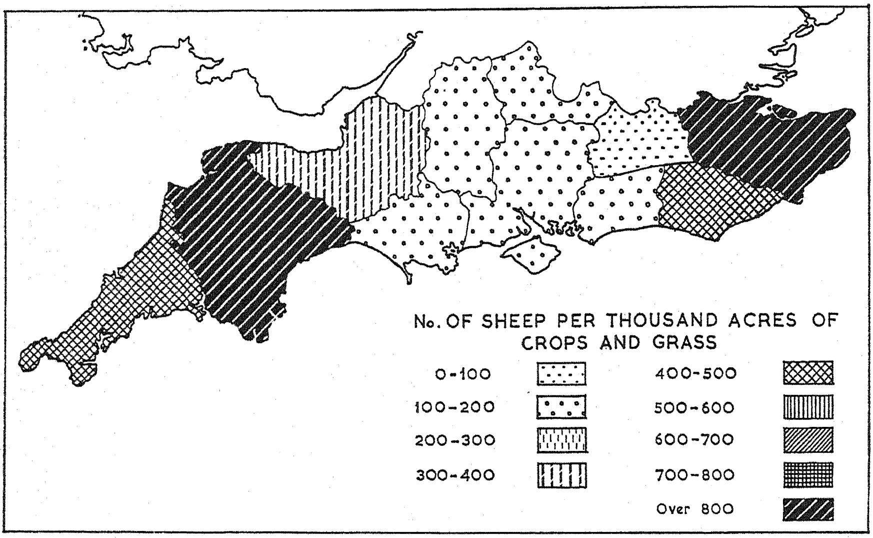


Fig. 99. DISTRIBUTIONAL MAP—THE SHADING METHOD.
To show the distribution of sheep in southern England for the year 1955.

The following figures—(*a*) as an average for four years, and (*b*) for a single year—on which Figs. 98 and 99 are based, emphasise certain defects of the shading method as do the Figs. themselves:

District	Average[1] 1952-5	1955
Cornwall	433	466
Devon	791	822
Somerset	366	386
Dorset	108	116
Wiltshire	100	133
Berkshire	84	102
Hampshire, exclusive of Isle of Wight	89	101
Isle of Wight	116	129
West Sussex	123	149
East Sussex	340	400
Surrey	69	82
Kent	760	855

[1] Average is per 1,000 acres of crops and grass.

Compared with Fig. 97, which is based on the absolute number of sheep in each county the shading method map shows an apparently equal distribution throughout a county, including areas like the New Forest, where there are few sheep. In any case, to appreciate the shading it is necessary to visualise the significance of the different shadings shown in the key and this is less easy than studying well-placed dots.

4. POPULATION MAPS

Statistics for a population map are obtained from census returns. Like crop and stock maps, population maps may represent either the number of persons per unit area or absolute figures derived from the actual population of towns and villages. In the former case, the shading or colour layer method is generally used; in the latter, use is made of the dot method or of some other type of symbols. In population maps the shading method has the disadvantage of giving a sense of uniformity to the distribution, and takes no account of the actual site of

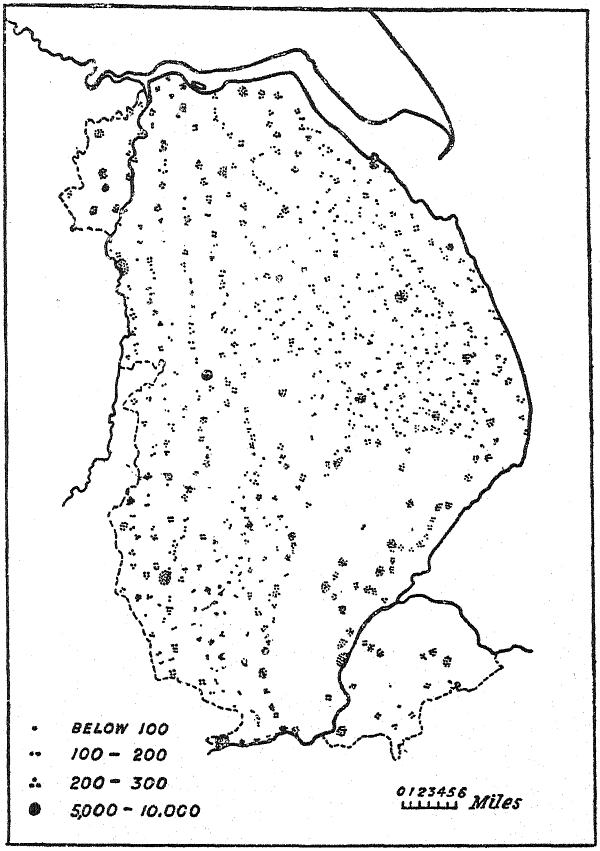


Fig. 100. DISTRIBUTIONAL MAPS—THE DOT METHOD.
To show the population of Lincolnshire, in 1801, when it was essentially a rural one.

settlements. The average for unpeopled moorlands like those of the Pennine plateaux is apparently the same as that for the more fertile dales with their villages and small market towns. This misleading uniformity is very apparent on small-scale maps, where it is not possible to make any distinctive symbols for towns.

The dot method, if the scale of the map is sufficiently large, and if a suitable unit is assigned to the dots, is more definite and more graphic. It has a concrete aspect, for we are dealing with the actual number of people and with actual sites. The 1-in. Ordnance map can be used as the basis for a population map where the dot method is used, for the sites of villages are shown with reasonable clarity. The general location of habitations and the sites of churches are shown, and dots can be placed to coincide with these.

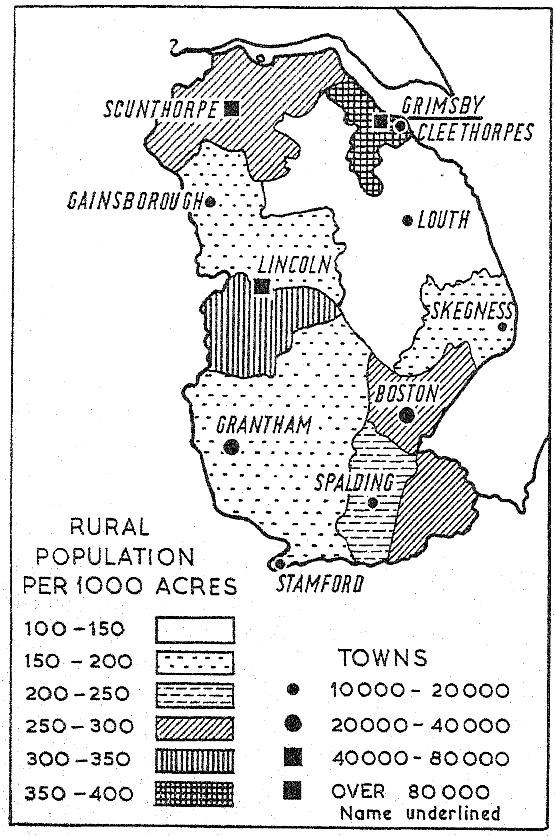


Fig. 101. Distributional Map—The Shading Method. To show the population of Lincolnshire in 1956. Towns are not included in the density shown by shading.

It is important to select the unit carefully. For a rural area, a dot might represent a hundred, or perhaps two hundred people, according to the size of the villages. These dots are put where the habitations occur, and it is possible to distribute them in a fairly accurate

way on a large-scale map. When preparing a skeleton tracing from the Ordnance map, it is well to pencil in lightly the habitations. The pencilled marks can afterwards be erased. If the area is mainly urban, or if any large towns occur so as to make it impossible to use the normal sized dots, other symbols must be used. Dots of varying sizes might represent places with 1,000, 5,000, or 10,000 people, in which case the size of the dot should be proportional to the number of people represented. If a dot of diameter $\frac{1}{30}$ in. is used to represent 100 people, the unit used to represent a town of 1,000 inhabitants should therefore be $1{,}000 \div 100 = 10$ times as large in area as the smaller dot, *i.e.* its diameter should be $\sqrt{10}$ times as great or $\sqrt{10}/30 = 0{\cdot}105$ in. Similarly, for a town of 10,000 inhabitants, the diameter of the representative circle would be $\sqrt{100}/30 = \frac{1}{3}$ in., etc. Special symbols such as squares and diamonds or "spheres" are sometimes used to show the larger towns in atlas maps, but these methods are not as satisfactory as the use of circles of various sizes.

A combination of the dot and shading methods is possible if we employ shading for averages without the inclusion of towns of a certain size, say those of 10,000 or 20,000 people upwards, merely using certain symbols for these larger towns. This method is possible for an area mainly rural, but with a few fairly large towns. It could be applied to Lincolnshire or Kent (Fig. 101).

Some population maps are constructed on a principle similar to a combined contoured and colour-layered relief map. On the map, lines known as *isopleths* pass through places with the same unit of population, *e.g.* hundreds, thousands, etc., according to relative density in the region, and in principle resemble contours. Between the isopleths various tints of selected colours give the layer effect. This method is used for the O.S. population map of Great Britain on a scale of 1/M, but it must not be confused with the shading method. In the latter the boundaries of the various kinds of shading are those of a parish or other political division, but in the isopleth method the isopleths are the boundaries of various colour-layer tints.

5. LIMITATIONS OF DISTRIBUTIONAL MAPS

Distributional maps are frequently important visual aids to grasping general ideas. It would be very difficult to gain such ideas from mere

columns of figures. However, there is danger that any distributional map may be taken too literally.

The value of statistics varies greatly. Distributional maps for crops and stock have only limited value, whatever statistics are used. The Ministry of Agriculture returns are for the whole year; they are supplied by individual farmers, whose returns are then grouped according to parishes. But in many parishes cattle are pastured during the summer and sent elsewhere to be fattened in fold-yards during winter. To give a truer picture, winter and summer stock maps would be desirable, but this is impossible, because such seasonal figures are not available. Numbers vary greatly from year to year, and a map founded on a single year's figures may not be in accord with normal conditions. Hence, it seems that from some points of view, maps might be better if based on statistics for an average term of years, say five. This would counteract any abnormal conditions due to an exceptionally good or bad year for crops or stock, and to some extent would allow for the effect of crop rotation. Averages may give a sense of artificiality and lack of reality, but to some extent this can be counteracted by special maps for abnormal years.

Population maps are often based on census returns which are made once in ten years. For some districts this may be misleading. Census figures for public institutions, barracks, holiday resorts, dormitory villages or suburbs, have obvious limitations, and deal with abnormal distribution of population.

Population maps compiled to represent so many persons per square mile, and prepared on the colour-layer or shading method, can be more misleading than similar maps for stock or crops, misleading as these often are. This is particularly the case when figures for several large towns are included in the average densities, or when a densely-populated district and an area of little economic value occur in the same administrative unit and jointly affect the average.

Reliable distributional maps must be based on wisely selected figures, whose accuracy and reliability have been carefully checked, and if necessary compiled in correlation with the physical or climate map.

Advanced students may with profit consult the Ordnance Survey Agricultural Atlas of England and Wales. The maps are compiled on the dot method, but only for a single year. They are reductions of a map

based on large-scale county maps showing individual parishes, the statistics used being for such units. Thus, the data are sufficiently detailed. The maps are on transparent paper, and in a pocket at the end of the atlas are relief, rainfall, and geological maps to use with the transparencies.

Comparison of the first and second editions of this atlas will show how maps based on figures for single years differ.

6. CLIMATIC MAPS AND DIAGRAMS

Climatic statistics form the basis of various types of maps. Mean monthly temperature, mean monthly pressure, form the basis of isotherm and isobar maps, for which purpose they are reduced to sea-level. They represent average conditions, whereas the ordinary weather map represents actual conditions at a given time. Mean monthly, mean annual, and mean seasonal rainfall figures form the basis of rainfall maps (see also p. 201).

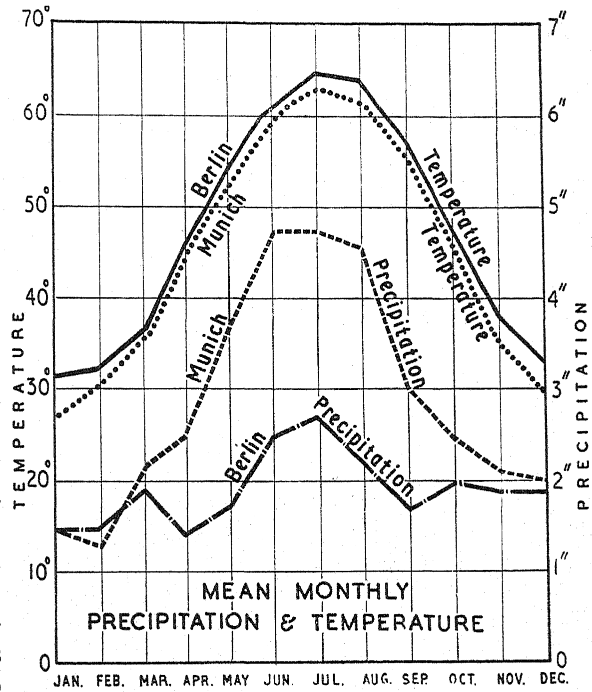


Fig. 102. See tables on page 169.

The practical construction of such maps resembles that of contoured maps, the figures for the various meteorological stations corresponding to the spot heights. In addition to their use for climate maps, temperature, pressure, and rainfall figures can be illustrated by various types of graphs.

The simple line graph is commonly used for this purpose. Mean monthly temperature and mean monthly rainfall can be easily shown.

In such graphs the months form the abscissae, the temperature or amount of rainfall the ordinates. Temperatures are usually shown by actual curves. In rainfall diagrams, the dots are often connected by straight lines, and are thus given a prominence which is not found in the case of a curve.

The mean monthly temperature curve is useful in gauging extremes of temperature. Temperature curves for a single month as well as for a year are possible, each day instead of each month being marked horizontally along the zero line. Similarly, temperature curves can be drawn for hourly readings throughout any day. Monthly or daily pressure charts are in like manner constructed from barometrical readings, but there has been considerable development in self-recording instruments which automatically record curves of temperatures and pressures, and thus enable observations of maxima and minima to be made.

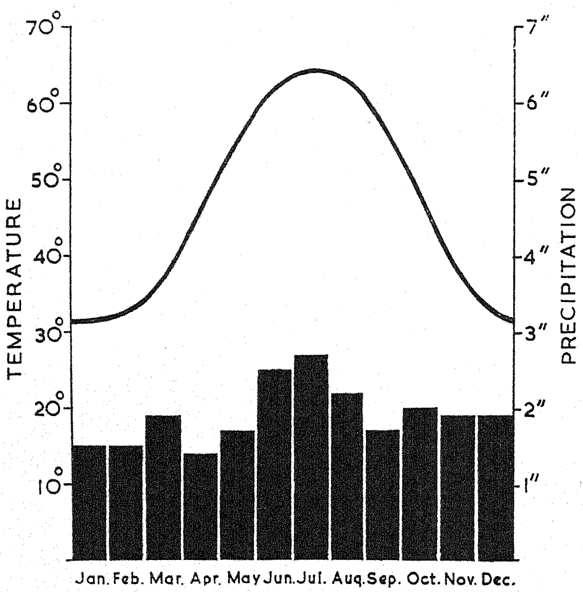


Fig. 103. MEAN MONTHLY PRECIPITATION AND TEMPERATURE OF BERLIN.

Mean monthly rainfall can be plotted absolutely, or as a percentage of the mean annual fall. The latter method shows at a glance the incidence of seasonal rainfall, and is frequently employed in the diagrams of advanced books like Kendrew's *Climates of the Continents*, and his *Climate*. The seasonal character of rainfall is an important aspect of climate in relation to crop production, and such diagrams are particularly useful in this respect.

Temperature and rainfall graphs may be plotted on the same diagram by placing the vertical temperature scale on the left of the diagram, and the rainfall scale on the right. Two or more temperature curves may be plotted on the same diagram for comparison, but care is necessary to prevent confusion and some distinction is usually made in the character of the curve lines, *e.g.* continuous, discontinuous, or dotted (see Fig. 102).

Rainfall is often shown by a bar graph, in which the column representing each month is blocked into the appropriate height. This is a suitable method of showing rainfall, which is measured from zero for each month as, to a certain extent, it gives a pictorial representation of the amount of rain which has fallen. It is particularly valuable when temperature and rainfall are shown on the same diagram as each can then be readily distinguished (see Fig. 102 and compare it with Fig. 103).

TABLES FROM WHICH CURVES IN FIGS. 102 AND 103 ARE PLOTTED.

BERLIN (Alt. 164 ft)

Month	Temp.	Precp.	Month	Temp.	Precp.
Jan.	31·3	1·5	July	64·4	2·7
Feb.	32·5	1·5	Aug.	63·3	2·2
March	37·0	1·9	Sept.	57·0	1·7
April	45·9	1·4	Oct.	48·2	2·0
May	54·9	1·7	Nov.	38·1	1·9
June	62·1	2·5	Dec.	32·7	1·9

MUNICH (Alt. 1,739 ft)

Month	Temp.	Precp.	Month	Temp.	Precp.
Jan.	27·3	1·5	July	63·0	4·8
Feb.	30·4	1·3	Aug.	61·5	4·6
March	36·1	2·2	Sept.	55·4	3·0
April	45·3	2·5	Oct.	46·0	2·5
May	53·1	3·9	Nov.	35·6	2·1
June	59·7	4·8	Dec.	28·6	2·0

Both are Central European types of climate. The altitude of Munich largely accounts for its lower temperatures and causes some relief rain. However, it is rather more accessible to Atlantic influences than is Berlin.

7. THE USE OF OTHER STATISTICAL DIAGRAMS IN GEOGRAPHY

Graphs and diagrams of various types are frequently used in geographical texts to avoid long written discussions and to give quick visual interpretation to tables of statistics. They can be used to compare amounts of one commodity produced by various countries, the variation in production of a single commodity in one place over a period of time, or the relative volume and value of various commodities to a single country. Population graphs are also useful. Almost any statistics can be represented graphically, in fact, but the value of the diagram produced depends on the suitability of the method by which it is constructed, for its particular purpose.

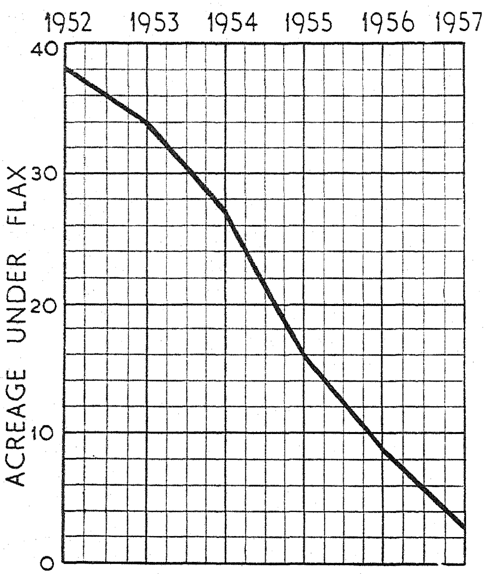


Fig. 104. AREA UNDER FLAX IN GREAT BRITAIN 12952-7 ('000 acres).

Year	Acreage	Year	Acreage
1952	38	1955	16
1953	34	1956	9
1954	27	1957	3

LINE AND BAR GRAPHS.—These graphs, which have already been mentioned as useful for climate statistics, can also be of value for economic ones. They are particularly suitable if we wish to consider variation over a period of time. If this variation is continuous, as in the case of population figures, a smooth curve should be used, if discontinuous, as in the production of wheat or steel, either a graph whose points are joined by distinct, straight lines (see Fig. 104) or a bar graph is better. Where the production of two or more commodities is to be simultaneously considered, the line graph is preferable to the bar graph as it is difficult to superimpose bar graphs on each other. For this type of graph, time should always be plotted along the abscissa (see Fig. 104).

ANOTHER USE OF BAR GRAPHS AND PIE GRAPHS.—Bar graphs are also frequently used to illustrate trade statistics and in this case the bars are often drawn horizontally instead of vertically. Fig. 105 is constructed on this principle from the statistics in the table on the opposite page, columns 1 and 3.

The bars of such a graph, may also be placed end to end (as in Fig. 106), in which case the total length of the bar represents the total production (or exports). A square or circle may be similarly divided and the latter is frequently used, divided into segments. In a "pie graph", as this is usually called, it is easy to compare the sizes of the segments within the circle but difficult to compare the sizes of segments in different circles. (In Fig. 107,

for example, the segments for Tanganyika are virtually the same size, as distinct from proportion, in each circle, although this is not readily apparent to the eye.)

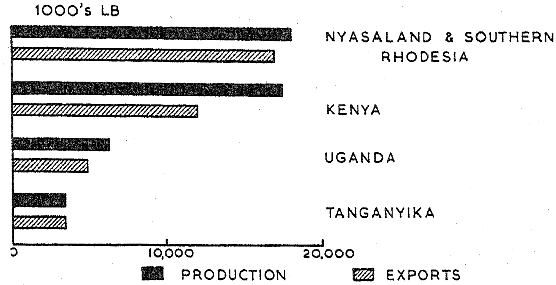


Fig. 105. Tea Production and Exports from British Colonial Africa, 1954.

To construct the pie graph (Fig. 107), the proportion of the whole production contributed by each country is calculated, and thence the angle of the sector as part of 360° by which it will be represented. *E.g.* for Nyasaland the angle will be $\frac{17183}{45379} \times 360° = 136{\cdot}3°$. These angles are shown in column 2 of the table below.

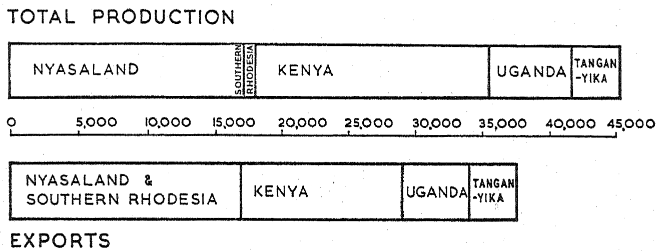


Fig. 106. Tea Production and Exports from British Colonial Africa, 1954 (in 1,000's of lb).

Tea Production and Exports from British Colonial Africa, 1954

Country	Production 1,000's lb.	Angle (Fig. 107)	Exports 1,000's lb.	Angle (Fig. 107)
Nyasaland ..	17,183	136·3°	17,112	163·9°
Southern Rhodesia	857	6·8°		
Kenya	17,490	138·8°	12,034	115·2°
Uganda	6,265	49·7°	4,929	47·2°
Tanganyika ..	3,584	28·4°	3,517	33·7°
Total	45,379	360°	37,592	360°

(The figures in this table, which are used for Figs. 105, 106, and 107, are taken from *The Times British Colonies Review*, Second Quarter, 1956.)

Since the exports are also to be compared with the production, the size of the second circle must also be calculated. This is done so that the *areas* of the two circles are proportional to the weight of tea in each case; thus the radius of the second circle is $\frac{\sqrt{37592}}{\sqrt{45379}} \times$ the radius of the first circle $(r) = 0{\cdot}72 \times r$. The angles by which each country will be represented are calculated as before and shown in column 4 of the table above.

By comparing Figs. 105, 106, and 107 the relative merits of these three types of diagram can be readily appreciated. In Fig. 105 it is easy to compare both production and exports between countries and the production

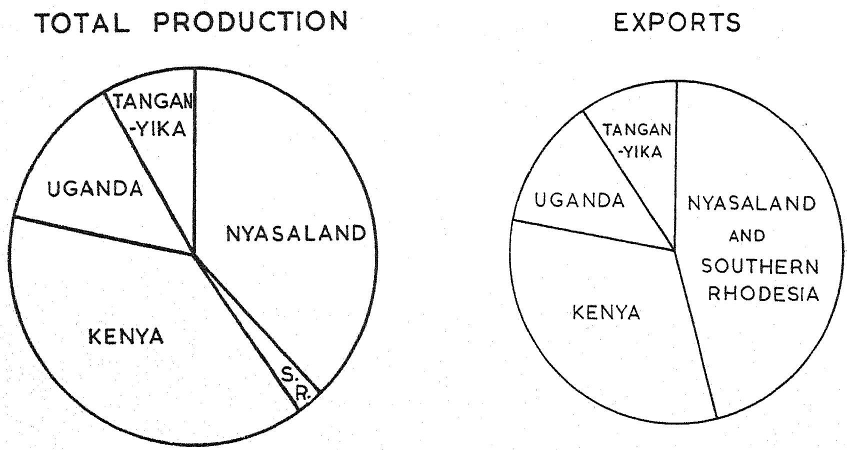


Fig. 107. TEA PRODUCTION AND EXPORTS FROM BRITISH COLONIAL AFRICA, 1954.

with the exports for each country, although it is not easy, at this scale, to do so very accurately. In Fig. 106 it is easier to compare the total production with the total exports, but less easy to compare the contributions made by individual countries to each. But in Fig. 107 comparison can most easily be made between these contributions to either production *or* exports. A single pie graph is, indeed, ideal for showing the contributions made by individual countries to world trade or production in a single commodity or for showing the relative importance of various commodities in the trade of one country.

PICTORIAL DIAGRAMS.—Pictorial symbols of various sizes, or groups of symbols of the same size, are sometimes used to illustrate trade and other statistics, but their accuracy is limited because of the difficulty of drawing them in correct proportions. Such diagrams are seldom used for geographical purposes, but are useful in advertising and propaganda material, where accuracy is of subsidiary importance to visual impression.

Note 1.—Fig. 100, in this chapter, and Fig. 96, are, with permission of Messrs. G. Routledge and Sons, Ltd, based on diagrams in the writer's *Eastern England.*

Note 2.—For very detailed treatment of various types of statistical diagrams see *Maps: Topographical and Statistical* by T. W. Birch.

EXERCISE VII

DISTRIBUTION MAPS

1. You have for a certain region—
   (i) A table showing the number of sheep per parish.
   (ii) Two distribution maps made respectively on the shading and dot method.
   (iii) A graph curve showing comparatively the number of sheep per parish.

Arrange the above in the order of what you deem to be their usefulness, giving reasons for your choice.

2. Treat, in like manner, similar data bearing upon the population of (*a*) Yorkshire, (*b*) Lincolnshire, (*c*) Cornwall, and say what factors here come in which do not concern us in data for crops and cattle.

N.B.—Treat each county as for a separate question and note any points connected with the distribution of population in each county.

3. Say how you would use an atlas vegetation map in connection with relief and climate maps of South America to suggest a division of that continent into broad natural regions. How may the vegetation map, if used alone, give a false or one-sided impression?

4. Describe the methods adopted for collecting data relative to the number and distribution of cattle and sheep in England and Wales. How can the available data be used for mapping the distribution of such stock? How far do you consider that such data and the maps which can be made from them fail to represent the normal distribution of stock in this country?

5. What are the chief difficulties and problems involved in the compilation of a population map (*a*) of England and Wales for reduction to a scale suitable for atlas purposes; (*b*) of a limited area, say a county or part of a large county on a scale of 1 : 63,360 for illustration of a regional essay? Suggest ways of overcoming or minimising such difficulties.

6. What are the chief difficulties as regards data for, and preparation of, maps to indicate temperature? Comment on the limitations of temperature maps.

7. Describe and criticise any cartographical methods you have seen in atlas maps and textbook diagrams designed to show density of population.

8. What types of map sometimes used to indicate density of population or stock fail to show adequately its distribution? Give reasons for such failure and suggest a remedy.

CHAPTER XV

WEATHER MAPS

1. EXPLANATION OF SYMBOLS ON WEATHER MAPS

Many daily papers now publish a **weather map,** which summarises the existing weather conditions over the British Isles and Western Europe, and gives a forecast of weather to be expected during the next twenty-four hours. In England the official weather maps, on which newspaper maps are based, are issued by the Meteorological Office. This is a Government Department under the Air Ministry, and employs a staff of highly trained scientists whose work is to compile and interpret the weather maps and to study weather conditions generally.

The official weather maps given in the *Daily Weather Report of the British Meteorological Office* are very interesting, and their cost is not great. They are supplied by the Meteorological Office for a relatively small subscription.[1] In order to derive the greatest possible benefit from these maps, careful study of the official handbook, *The Weather Map* (H.M.S.O.), is recommended.

An explanation of the various symbols used on weather maps in the *Daily Weather Report* is given below. Further information regarding symbols is given in an Air Ministry publication entitled *Instructions for the Preparation of Weather Maps* (H.M.S.O.) but this is mainly concerned with the plotting of the much more detailed information shown on the large working charts prepared for use in the meteorological offices themselves.

General

Barometer. Isobars are drawn for intervals of four millibars.

Wind. Arrows fly with wind. A full-length feather represents 10 knots and a short feather 5 knots. A solid pennant represents 50 knots. Calm is indicated by circle outside weather symbol: ◎

Temperature for British stations was given in degrees Fahrenheit until 1961 but is now stated in degrees Celsius ("centigrade") to conform to international usage.

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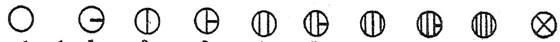
[1] Details of this service can be obtained from The Director, Meteorological Office, Air Ministry, Adastral House, Kingsway, London, W.C.2.

CLOUD AMOUNT.



No cloud $\frac{1}{8}$ $\frac{2}{8}$ $\frac{3}{8}$ $\frac{4}{8}$ $\frac{5}{8}$ $\frac{6}{8}$ $\frac{7}{8}$ $\frac{8}{8}$ Sky obscured

WEATHER SYMBOLS. ● Rain ⁎ Snow ● ⁎ Sleet , Drizzle ▽ Shower

≡ Fog = Mist Thunderstorm

THE BEAUFORT WIND SCALE

Beaufort Number	Wind	Speed Knots	Speed m.p.h.	Commonly Observed Effects of Corresponding Winds
0	Calm	< 1	< 1	Calm, smoke rises vertically.
1	Light air	1-3	1-3	Direction of wind shown by smoke drift, but not by wind vanes.
2	Light breeze ..	4-6	4-7	Wind felt on face; leaves rustle; ordinary vane moved by wind.
3	Gentle breeze ..	7-10	8-12	Leaves and small twigs in constant motion; wind extends light flag.
4	Moderate breeze ..	11-16	13-18	Raises dust and loose paper; small branches are moved.
5	Fresh breeze ..	17-21	19-24	Small trees in leaf begin to sway, crested wavelets form on inland waters.
6	Strong breeze ..	22-27	25-31	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty.
7	Near gale ..	28-33	32-38	Whole trees in motion; inconvenience felt when walking against wind.
8	Gale	34-40	39-46	Breaks twigs off trees; generally impedes progress.
9	Strong gale ..	41-47	47-54	Slight structural damage occurs (chimney pots and slates removed).
10	Storm	48-55	55-63	Seldom experienced inland; trees uprooted; considerable structural damage occurs.
11	Violent storm ..	56-63	64-72	Very rarely experienced; accompanied by widespread damage.
12	Hurricane	above 64	above 73	Countryside devastated.

These velocities refer to 30 ft above ground.

2. IMPORTANT TERMS

Before considering types of weather maps and their interpretation, it is well to note the meaning of certain terms used in connection with such maps.

BAROMETRIC PRESSURE.—Air has weight, therefore it must press upon the earth, and the pressure at any point of the earth's surface is influenced by the

quantity of air above. Pressure at the foot of a mountain is greater than at the top; but at sea-level pressure varies at different places and at the same place at different times. Such variation is largely associated with changes of temperature, because the density of air is affected by temperature. Hence temperature readings find a place on weather maps.

Atmospheric pressure is measured by the barometer. The pressure of the atmosphere is the same as would be the pressure exerted by a layer of mercury as deep as the mercury column in the barometer is high. It is usual to state the pressure of the atmosphere in inches or millimetres of mercury, and such are termed barometric readings. The density of mercury can be found, and it is easy to convert this into units of weight per unit of area. The average pressure at sea level is 29·9 in., which represents about 14·7 lb./sq. in. Formerly, barometric pressures on weather maps were expressed in inches, but now they are indicated in "millibars", one thousand millibars being equivalent to 29·53 in. of mercury. Conversion of inches into millibars or vice versa is a matter of simple proportion, for instance, 950 millibars = 28·05 in.; 1,050 millibars = 31·01 in.

ISOBARS.—Isobars are lines of equal barometric pressure, being drawn through places where the pressure (reduced to sea-level equivalent) is the same. They can be compared with contours, the "vertical interval" generally being 4 millibars, which corresponds to about $\frac{1}{8}$ in. of mercury.

BAROMETRIC GRADIENT.—The barometric gradient is the rate of fall of barometric pressure measured at right angles to the isobars. The unit of barometric gradient is a fall of $\frac{1}{100}$ in. in 15 nautical miles. Thus, if isobars 30·1 and 30·3 are 20 nautical miles apart (measured at right angles to the isobars) the gradient is $\frac{20}{100}$ in. in 20 ml., or $\frac{15}{100}$ in. in 15 ml., that is, it will be 15. Where isobars are close together and the gradient is thus high, winds are strong; where isobars are far apart and the gradient is low, winds are light.

ISOTHERMS.—Isotherms, or lines of equal temperature, are drawn through places having the same temperature *when reduced to sea level.* On British weather maps temperature is shown in degrees Celsius, but the isotherms are not actually drawn, the temperature readings only being inserted on the site of each meteorological station. However *mean* Sea Surface isotherms

for the corresponding month are shown on maps in the *Daily Weather Report* at intervals of five degrees C. Isotherm maps are associated with climate rather than with weather.

ISOHYETS.—Isohyets, or lines of equal rainfall, are drawn through places having the same amount of rainfall for a given period: month, season, or year, as the case may be. It is obviously impossible to draw them with any accuracy on weather maps, which usually indicate the weather for a period of twenty-four hours. On weather maps, a special symbol is used to show that rain is falling at a given station, and other symbols are used to indicate to what extent the sky is clouded. There are also symbols for snow, hail, fog, mist, and other meteorological phenomena.

ISALLOBARS.—These are lines drawn through places where the barometer has risen or fallen by the same amount during the preceding three hours. Inset maps showing isallobars may be given on weather maps, and are useful for comparing the barometric rise or fall at different places.

DEPRESSIONS AND ANTICYCLONES.—A depression (or cyclone) (Figs. 122 and 127) is an area of low pressure surrounded by high pressure. An anticyclone (Fig. 118) is an area of high pressure surrounded by low. Weather reports to-day refer to "depressions" rather than "cyclones", the latter term being considered more suitable for certain tropical storms.

3. RAW MATERIAL OF THE WEATHER MAP

A weather map may represent conditions (*a*) at a given instant of time, *e.g.* the daily weather map of Britain or the U.S.A.; (*b*) average weather over a period, *e.g.* over a month or year. Maps of the latter type deal with climate rather than weather, climate being the sum total of average weather conditions. Weather may refer to the state of the sky, *e.g.* cloudiness, rain, snow, mist, fog, etc.; the temperature and humidity of the air; wind, its direction and strength; and, especially for aviation, visibility. Previous to the construction of a weather map, careful and systematic observations of most of these items are necessary. In connection with such maps, there is a type of observation, not of actual weather conditions, but important as a key to them, viz. barometric pressures.

It was in 1860 that the first official observations were dealt with by the Meteorological Office, which had been formed a few years previously.

The first official weather maps were made in 1872. It was not until the latter part of the nineteenth century that results of observations were received from stations in Central Europe. At the beginning of the 1914-18 War, results of fairly full observations were received from the Azores, the continent of Europe, and ships at sea, and use was made of wireless telegraphy. The needs of aircraft, etc., made it necessary during the War to develop more thorough observations of the upper atmosphere, and, as a result, considerable progress was made in forecasting. Further advances were made in 1939-45 and for similar reasons.

Most countries especially in Europe and North America, maintain many observing stations, which at agreed hours in the twenty-four, make observations, the times being fixed by international agreement. Results of these observations are reported by ordinary or wireless telegraphy to the central office in each country, from which they may be sent abroad.

At the fixed hour, the trained observer goes out, notes the state of sky, the amount and type of cloud; any precipitation; the nature of the visibility; also the direction and strength of the wind (unless there is a wind recorder); the temperature and humidity from readings of the thermometers in the Stevenson screen; he reads the barometer or barograph. Twice a day he examines the rain gauge and measures the amount fallen. All these results are transmitted by code. At the internationally agreed hours, ships at sea, including a number of "weather ships", manned by meterological personnel, which patrol particular areas, take as many observations as possible, and transmit them by wireless, giving their position; these results are picked up by land stations and sent to the Central Office. Twice daily, the U.S.A. sends a wireless report of conditions in the U.S. and Canada. Here are the essentials for making a map, founded on periodical observations. These observations must be made and recorded scientifically, *i.e.* instruments must be accurate, observations must be made accurately and simultaneously. Regular and speedy transmission of news to the Central Office is necessary. Also, there must be uniformity in methods of observation.

4. THE POLAR FRONT THEORY

For an understanding of certain of the weather maps given on subsequent pages, it is necessary to grasp the *Polar Front Theory*, now generally used to explain the origin and character of depressions. The theory

asserts that masses of relatively warm and cold air are brought into contact. These masses are known as polar and tropical air, from their source of origin. Polar continental air is cold and dry, tropical maritime air is warm and moist. These masses of air flow is roughly parallel, but in opposite directions, respectively from north-east to south-west and south-west to north-east (Fig. 108). The line of separation is termed the **polar front.** The streams of warm and cold air do not always maintain the directions shown in Fig. 108. When a depression is forming a bulge of warm air develops towards the north, and the warm air pushes up into the cold, as shown in Fig. 109, where the broken line represents the approximate position of the polar front before this movement took place. At the forward boundary of this bulge, or **warm sector** as it is called, warm air is blowing against colder heavier air and gradually rising over it. At the rearward boundary of the warm sector heavier colder air begins to undercut the warm air and to lift it off the ground (Fig. 110). At the same time, the warm sector as a whole moves forward with the depression of which it forms a part, and rotates very slowly about the centre of its depression.

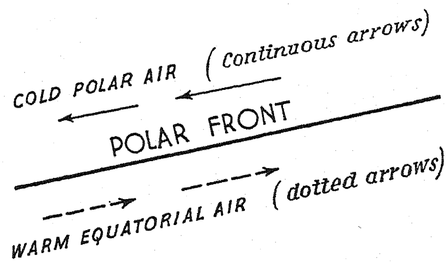


Fig. 108. DIAGRAMMATIC REPRESENTATION OF THE POLAR FRONT.

(Theoretical idea. Conditions are never stable.)

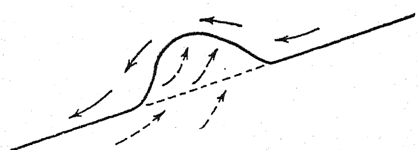


Fig. 109.

As the forward boundary of the warm sector reaches a given place the colder air in front of the warm sector is replaced at that place by warmer air. Hence the forward boundary of a warm sector is called a **warm front,** since its passage is accompanied by a rise in temperature. At the rearward boundary of the warm sector warm air is being replaced by colder air, and this boundary is called a **cold front.**

The cold front of a warm sector moves forward at a greater speed than the corresponding warm front, so that the cold front gradually overtakes the warm front and the warm sector decreases in size as more and more

of the warm air is lifted right off the ground (Fig. 111). This occurs first at the tip of the warm sector. When the warm air has been lifted off all the ground the warm sector is said to be **occluded,** and the line along which the

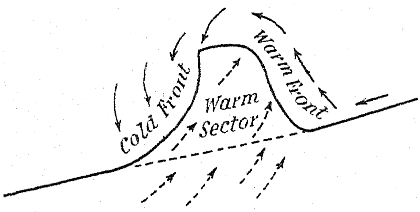


Fig. 110.

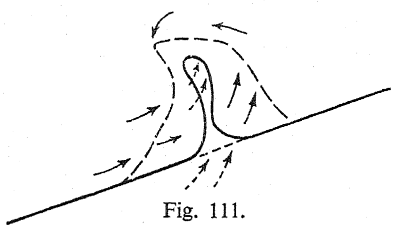


Fig. 111.

warm air left the ground is spoken of as an **occluded front** or more briefly as an **occlusion.**

The position of fronts is marked on weather maps by lines of rounded or pointed "teeth". Rounded teeth (a scalloped edge) are used for warm

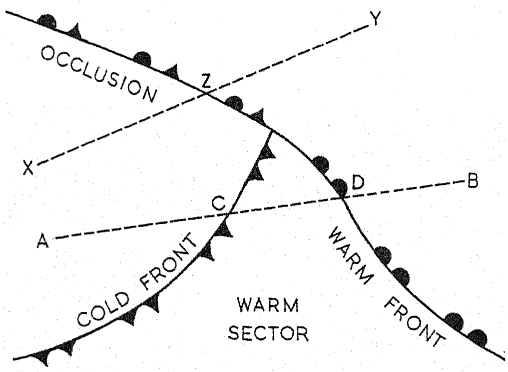


Fig. 112. Diagrammatic Representation of Fronts on a Weather Map.
The lines AB and XY are the direction of the elevations shown in Figs. 113 and 114 respectively.

fronts, pointed teeth for cold fronts, and alternate rounded and pointed teeth for occlusions (Fig. 112). In each case the teeth point in the direction in which the front is moving.

As the warm air slides up over colder air at a warm front, the air cools and condensation of water vapour occurs, with the formation of clouds

and, later, rain. Similarly clouds are formed at the cold front where warm air is being undercut by the colder air behind the front, but the upward movement of the warm air is not so smooth and regular here as at the warm front and so we tend to get shower and thunder clouds with a cold front, instead of the layer or sheet clouds associated with a warm front (Fig. 113).

5. **WEATHER ASSOCIATED WITH DEPRESSIONS** (Figs. 119, 122, 125, 127)

The isobars of a depression, sometimes known as a cyclone, a term, however, better reserved for a type of tropical storm, are roughly circular or oval, with isobars of lowest pressure inside. The size of depressions varies greatly; the height is relatively small. A depression is seldom

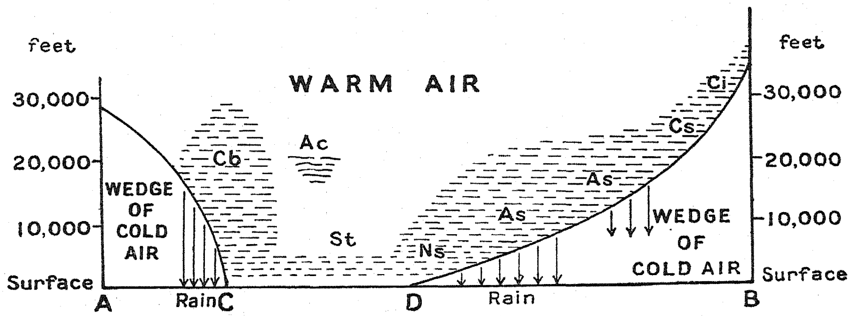


Fig. 113. Elevation along line AB in Fig. 112, showing cloud types in warm sector. Note that the vertical scale has been greatly exaggerated in proportion to the horizontal scale: DB may represent a distance of perhaps 500 or 600 miles.

Ci, cirrus; Cs, cirro-stratus; As, alto-stratus; Ns, nimbo-stratus; St, stratus; Ac, alto-cumulus; Cb, cumulo-nimbus.

stationary. In general, the movement of depressions in north-west Europe is usually in an easterly direction. The direction of movement of a given depression on a weather map is usually the same as the direction of the isobars in the warm sector, and also is in the direction in which the fall of pressure is most rapid (as indicated by the barometric tendencies shown for the various reporting stations).

The first sign of an approaching depression will be cirrus clouds, which give place to cirro-stratus, and these in turn to alto-stratus, followed by nimbo-stratus and rain. During this period the barometer falls steadily, but visibility is good until rain falls. *Cirrus* clouds are detached clouds of

delicate and fibrous appearance, generally white; *cirro-stratus* is a thin, whitish veil which does not blur the outline of the sun or moon, but produces halos; *alto-stratus* resembles a fibrous veil, grey or bluish; *nimbo-stratus* is a low, amorphous layer, dark grey in colour.

When the warm front arrives, temperature will rise, wind will veer, *i.e.* change direction clockwise, and pressure continue to fall, but more slowly. Rain, at first intermittent and then continuous as the warm front approaches, ceases or becomes a drizzle after passage of the warm front. Visibility is poor, possibly with fog or mist. Cloud will be stratus, *i.e.* a uniform layer of cloud resembling fog but not resting on the ground, or alto-stratus. During passage of the warm sector temperature is usually fairly constant and there is drizzle rather than rain. During passage of the cold front temperature falls quickly, wind veers, and there may be squalls; there is heavy rain, perhaps with hail or thunder, pressure rises, and visibility is usually poor. Visibility rapidly becomes good or very good after passage of the cold front. In the cold air behind the cold front continuous rain soon stops, but there may be occasional rain showers, with less cloud. This is a general and necessarily an "ideal" description of a polar front depression, and individual depressions will, of course, vary in some details.

6. WEATHER ASSOCIATED WITH ANTICYCLONES (Figs. 118, 120, 123, 124, 126)

An anticyclone or "high" (*i.e.* high pressure area) is an area of high pressure surrounded by low. Isobars near the centre of an anticyclone are generally wide apart, and thus indicate light winds, and anywhere in the anticyclone the winds are rarely of more than moderate strength. In connection with anticyclones it is useful to consider lapse-rate in conjunction with stability and instability. *Lapse-rate* is the rate of fall of temperature with increasing height, and can be measured anywhere, *e.g.* we could speak of the average lapse-rate in the first fifty feet from the ground. A negative lapse-rate, *i.e.* temperature increasing with height, is called an *inversion.* This term is also sometimes used for the level at which the maximum temperature occurs. The average lapse-rate is 3·3° F. per 1,000 ft. Air having a low lapse-rate is relatively stable, and air with a high lapse-rate, *e.g.* polar air, is unstable and gives showers, etc. An inversion has important effect on weather, because it renders the air very stable, so that rising air cannot

penetrate the inversion but is forced to spread out when it reaches the inversion layer. In anticyclones there is an inversion well above the surface. If the rising air contains cloud the cloud will also spread out in sheet form. Under such conditions the very fine water droplets that form the clouds are unable to coalesce sufficiently to produce drops large enough to fall as rain. Hence we understand why rain seldom falls in a well-marked anticyclone, although drizzle may occur, with dull overcast skies.

In middle latitudes anticyclones can be classed as cold or warm. The former occur when cold air moves southward in the rear of a family of depressions, the greater density of this cold air causing increase of pressure. They are essentially of maritime origin, as their association with depressions shows. They seldom last beyond a few days, but over the land the winter cooling of the earth's surface may prolong them. Warm anticyclones may be (*a*) an extension from the subtropical high (the Azores High), or (*b*) a development from a cold anticyclone. In summer, type (*a*) results in a spell of fine warm weather over the land, but at sea often causes fogs during spring and summer. Under these conditions fogs are also caused by cooling due to radiation over the land in winter.

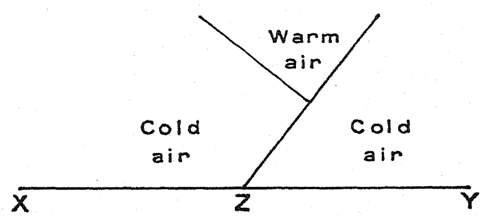


Fig. 114. Elevation along line XY in Fig. 112—an Occlusion.

There are thus two types of anticyclone; both give quiet weather. One has little cloud, hence a heat wave in summer or a cold spell of severe weather in winter. (Clear skies give heat waves in summer because there is no "cloud blanket" to check free play of the sun's rays, and cold spells in winter because there is no cloud to check loss of heat by radiation during the long nights.) The other may in winter result in long spells of still, damp, foggy days, or long still periods with dull, overcast skies.

7. OTHER PRESSURE SYSTEMS AND THEIR WEATHER CONDITIONS

THE SECONDARY DEPRESSION.—This is a low-pressure system associated with a bigger one. Secondaries vary in intensity from just a slight bend in the

isobars to a system that contains closed isobars with steep gradients and well-developed winds. They form in any part of a depression, but develop mostly on the southern side. They cause increased wind on the side furthest from the main depression, and have their own wind circulation apart from that of the main one. The easterly winds on the north side are less strong than the westerly winds on the south side, and some of our strongest winds are associated with secondaries. This is because the centre of a primary depression is often north-west of Britain, so that we escape winds from the primary, but receive those of the secondary. The southerly gales in front, and the westerly gales on the south are strong and often do damage. The weather in a secondary is similar to that of a primary—warm and cold fronts giving clouds and rain. Secondaries more frequently cross Britain than do primary depressions, as series of them often move anti-clockwise round a primary (Fig. 116).

A TROUGH OF LOW PRESSURE, formerly known as a "V-shaped depression", is associated with the warm or cold front of a depression. The warm front type may give persistent rain before the depression passes, with mild, cloudy weather behind. The cold front type will cause clearing-showers with bright skies and cooler weather. Troughs are sometimes found without an associated front. A deterioration of weather is usually found with non-frontal troughs.

A RIDGE, formerly known as a "wedge", is a region of high pressure where the isobars take the form of an inverted V. Pressure is high within the V; a ridge usually projects north from a high-pressure area, and has lows to the east and west. It generally moves east with depressions and wears away. Ridges are usually regions of fine weather (Fig. 117).

THE COL.—A col is a central region between two highs and two lows. In a col, conditions are neither cyclonic nor anticyclonic, but it is a region of calm. In winter, weather is calm and foggy; in summer, if the sky is clear, there may be thunderstorms. It is a kind of "neutral" region (Fig. 121).

8. FORECASTING

Modern weather forecasting is primarily based on (1) the study of air masses, particularly their relation to one another; and (2) their physical

properties, especially temperature, humidity, and pressure. Air masses are classified according to their place of origin, *e.g.* air of what is broadly termed (*a*) polar, (*b*) tropical origin. Each of these cold or warm air masses may be subdivided into (1) maritime or (2) continental air, again according to origin. The origin of air masses can be inferred from their properties—temperature, dew point, lapse-rate, etc. The last-named is found from upper air observation by aircraft, or radio sondes. A radio sonde is a balloon carrying meteorological instruments and a small radio-transmitter which relays their readings. A lapse-rate can also sometimes be inferred from surface phenomena, *e.g.* a showery type of weather is associated with polar air, unstable owing to its high lapse-rate.

Once the fronts have been identified on the map the isobars are sketched in from the pressure readings and wind directions. Surface winds blow roughly parallel to the isobars but somewhat deflected towards the lower pressure. The amount of deflection, or "backing", is smaller the stronger the wind. Strong winds occur when the barometric gradient is steep, *i.e.* when the isobars are close together. At inland stations wind direction is sometimes rather variable, especially with light winds, owing to differences in exposure of the observing stations. Since the passage of a well-marked front is accompanied by a sudden veer of the wind, isobars show a discontinuity in direction as they cross a front, unless this is stationary. Wind direction is usually the same throughout a warm sector, and in such cases the isobars in the warm sector are shown as parallel straight lines.

The forecaster will have to estimate the direction and rate of movement of each front. When this has been done, he is in a position to judge when the conditions associated with these fronts may be expected to reach the area for which he is forecasting. Such a forecast as "Rain spreading eastwards across area" will have been based on the identification of a warm front or occlusion approaching the area from the west. The speed at which the front is moving will have been estimated from the distance it has travelled between successive charts (which in British forecast offices are drawn every three hours) or from the speed of the upper winds.

Very detailed and accurate forecasts over wide areas are possible for a few hours ahead and are of great value for aviation purposes, but in Western European areas the forecasting of conditions for more than twenty-four hours ahead usually involves an appreciable element of doubt. To understand

why this is so, let us consider a particular case. Let us suppose that the forecaster has identified a secondary depression out in the Atlantic which, on the basis of the necessarily somewhat scanty reports from such an area, he estimates to be travelling towards the mouth of the English Channel at, say, 35 m.p.h. (speeds of 50-60 m.p.h. are by no means rare). In twenty-four hours this depression will have travelled nearly 1,000 miles. The centre of the depression may now be moving across northern France, or up the Channel, or across southern England, or the depression may have turned northwards and be moving up the Irish Sea. The forecaster is aware of these possibilities and of the very different weather they would bring to, say, southern England, but the information at his disposal when he has to issue his forecast rarely permits him to do more than select the most probable of the various possibilities. In special circumstances, more particularly during anticyclonic weather, it is possible to issue satisfactory forecasts for two or three days ahead.

The following maps, with the notes on them, illustrating typical weather conditions, are adapted from *The Weather Map*, by kind permission of the Director of the Meteorological Office and the Controller, H.M. Stationery Office. Acknowledgement is also made to *Meteorology for Aviators* by Dr R. C. Sutcliffe and to *Weather Study* by Professor Sir David Brunt.

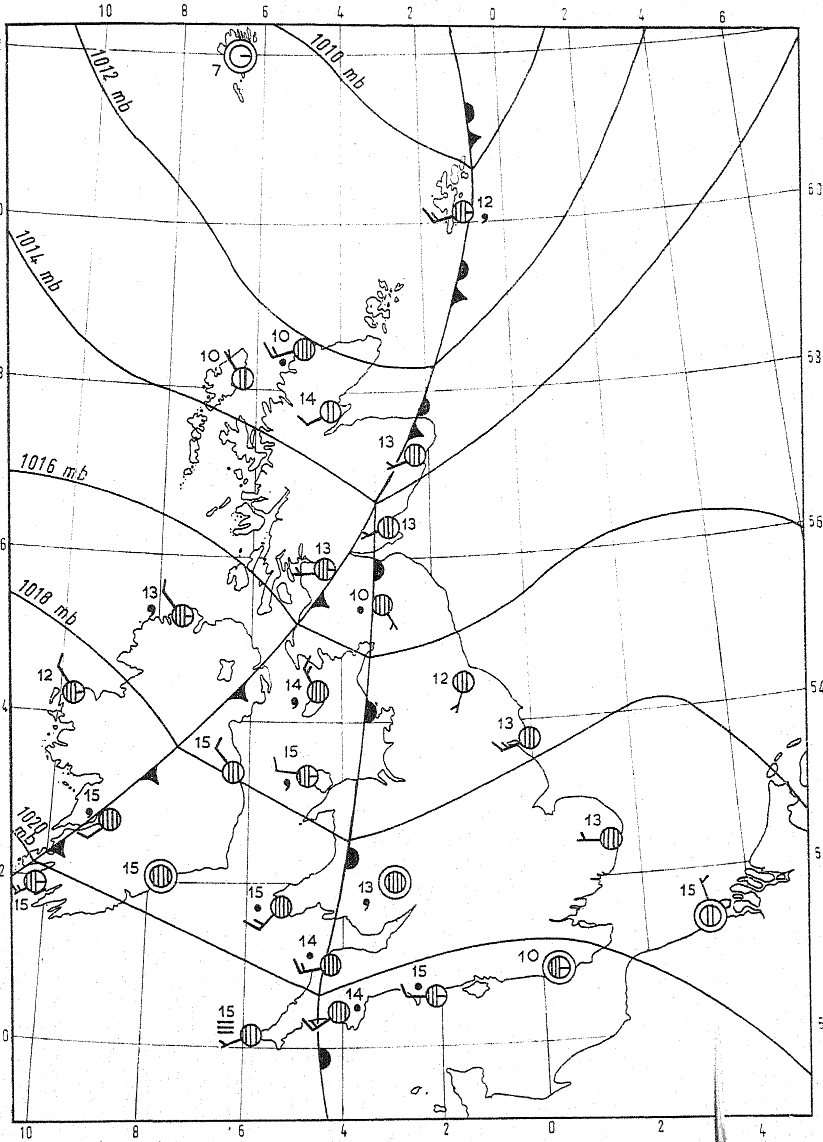


Fig. 115.

22nd August, 07 hr. A weak frontal trough of low pressure is cr[illegible]ing the British Isles. A belt of rain or drizzle with very low cloud and hill [illegible] across south and east Scotland, north England, Wales, and south-west England, w[illegible]ll move steadily south-east. Behind this rain belt, weather will become sho[illegible]y with bright intervals. It will be close at first becoming cooler.

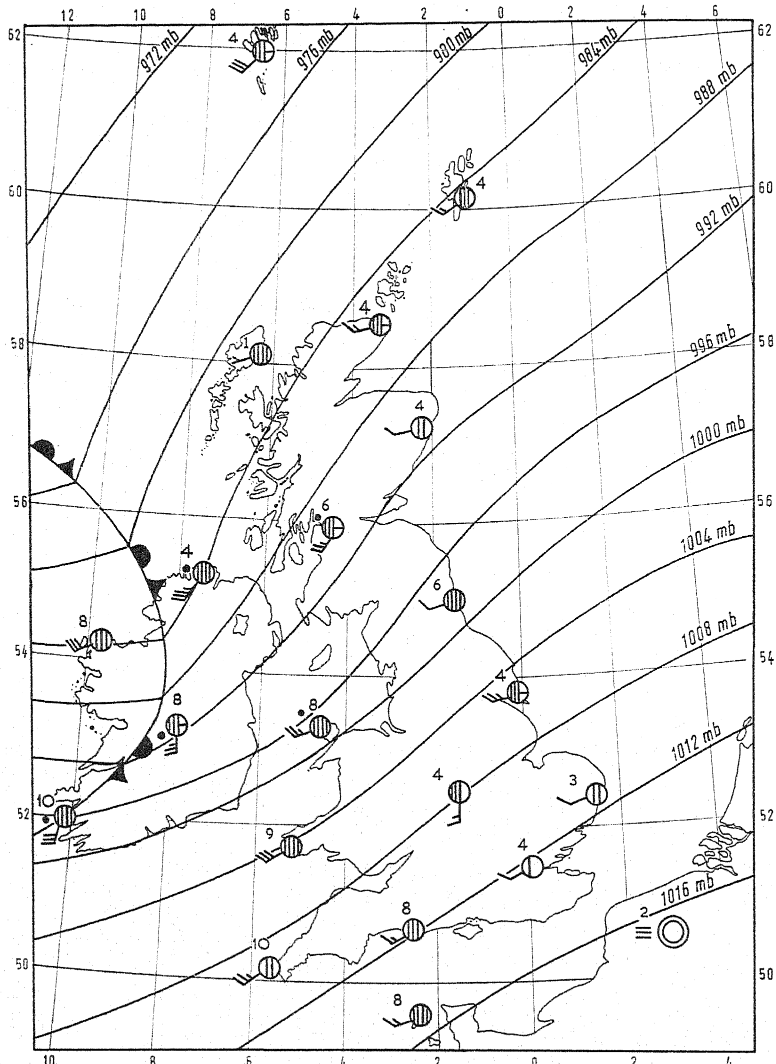


Fig. 116.

10th January, 07 hr. An intense secondary depression off the Hebrides will move rapidly north-eastwards, while the primary off southern Iceland is tending to move a little south-east. Weather will continue stormy and unsettled and gales will be rather severe to-day in most northern districts. Further outlook: Stormy and unsettled but considerable bright periods in the south and east of England. Snow showers on high ground in the north.

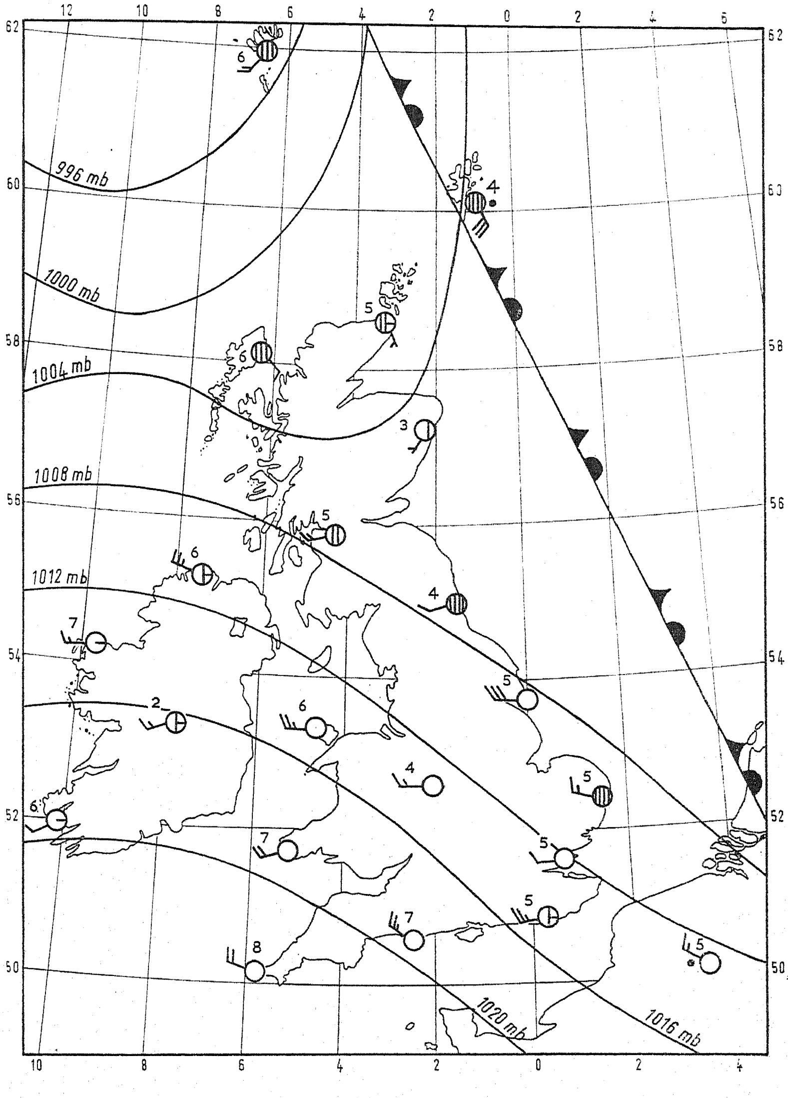


Fig. 117.

19th January, 07 hr. A ridge of high pressure crossing the British Isles will give a short, fine interval, but a deep depression on the Atlantic will soon extend its influence over the British Isles.

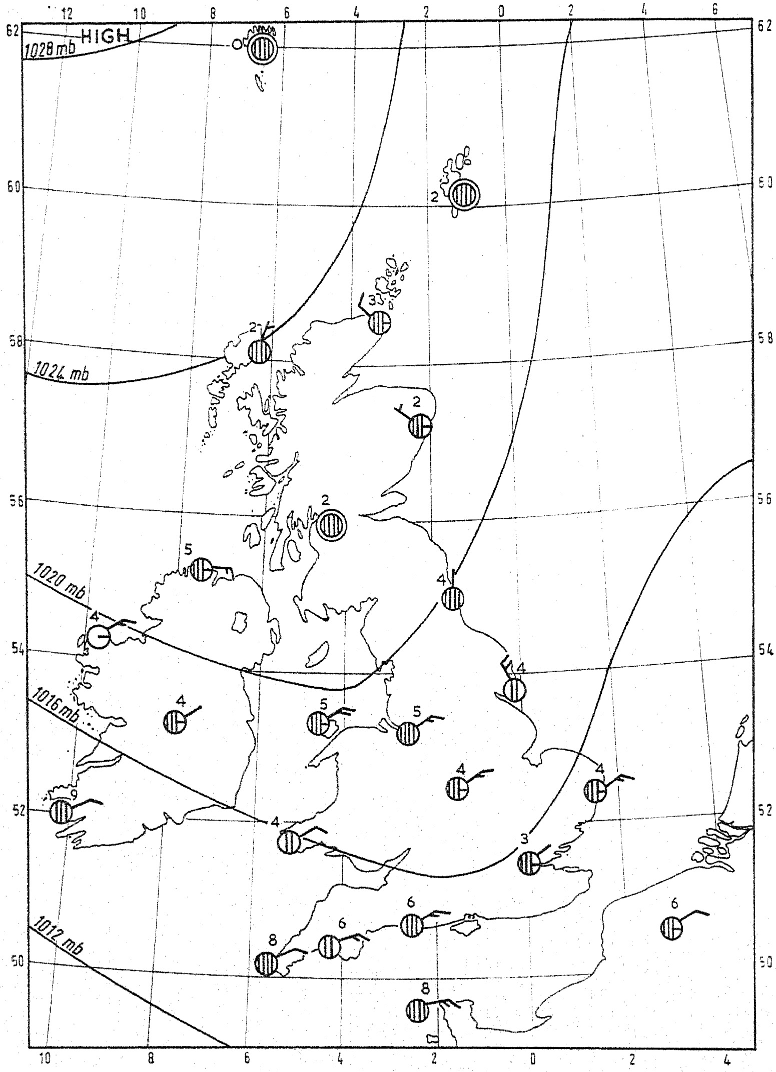


Fig. 118.

8th March, 07 hr. A large anticyclone over Iceland has extended its influence over the British Isles. Winds will be north-easterly and weather mainly cloudy and cold with local showers of rain or sleet, chiefly near the east coast.

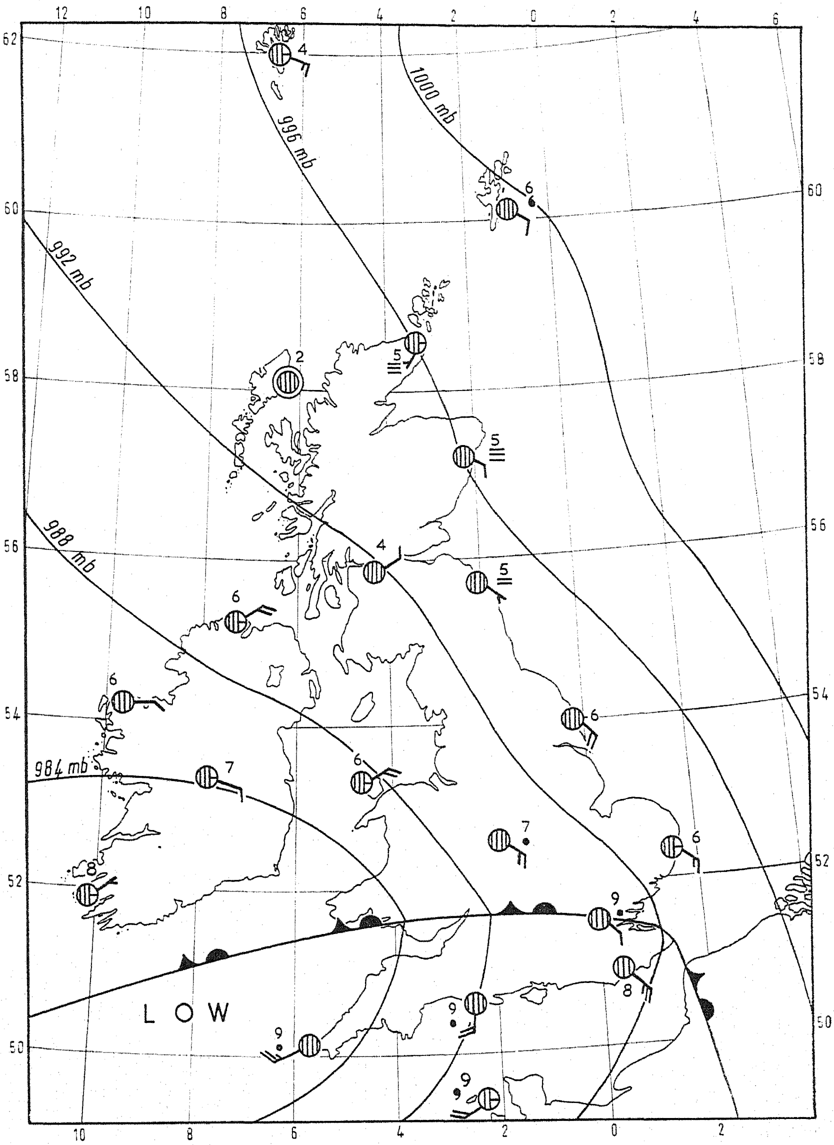


Fig. 119.

23rd March, 07 hr. A deep depression centred north of Scilly is moving slowly north-east and filling up. A rain area now over southern England will move northwards followed by showers and bright intervals.

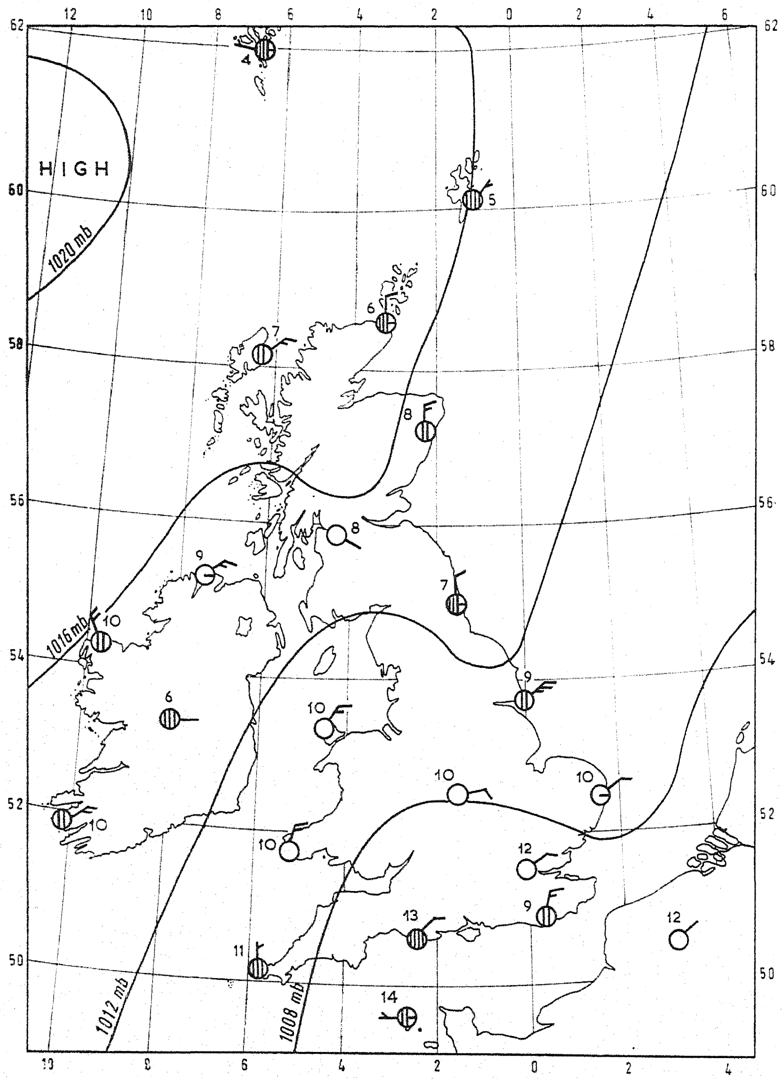


Fig. 120.

7th May, 07 hr. An anticyclone is centred off the Hebrides. Winds will be from a northerly point and the weather will be mainly fair. Temperature will be considerably lower than of late, with ground frost in many places by night.

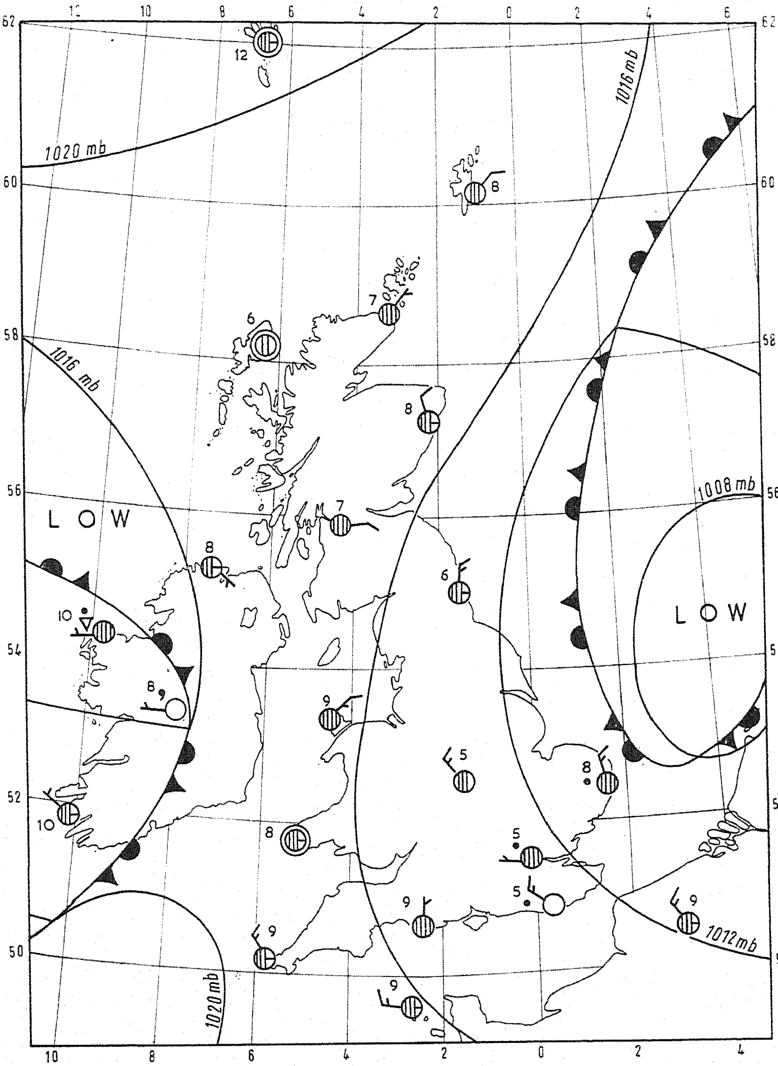


Fig. 121.

23rd May, 07 hr. A depression off the Irish coast is moving slowly south-eastwards whilst another persists over the southern North Sea. Unsettled weather will continue with rain or showers in most districts except the extreme north of Scotland, but the temperature will be somewhat higher than of late. Further outlook: Unsettled.

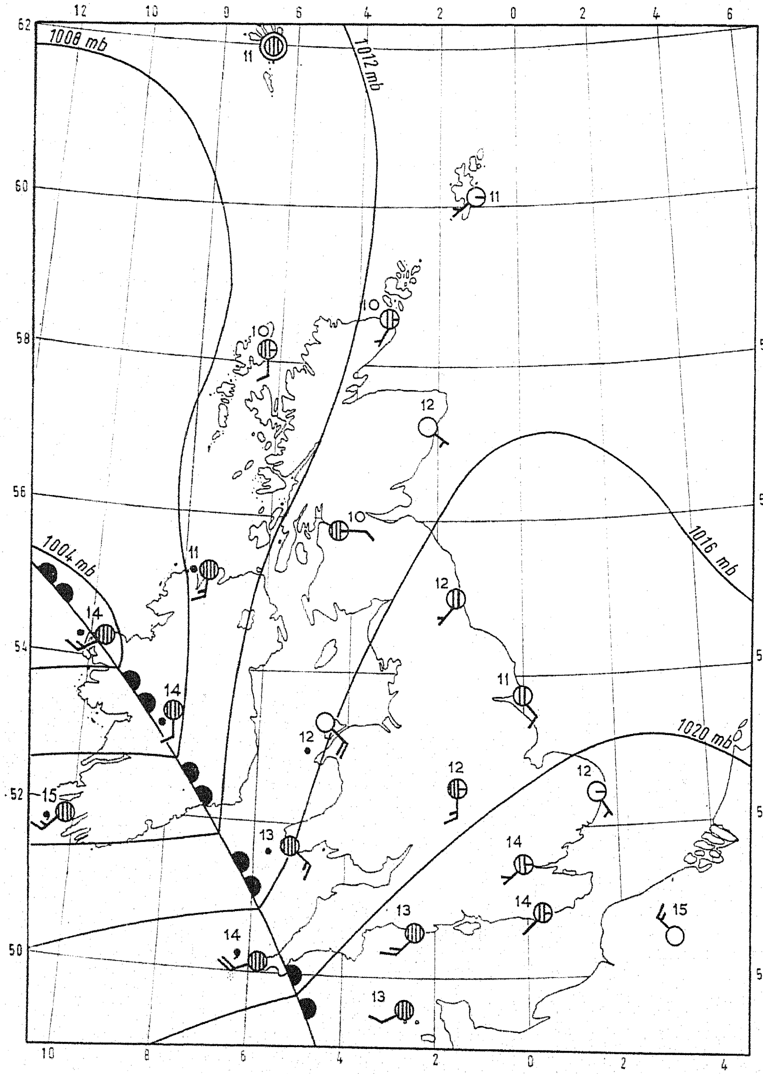


Fig. 122.

21st June, 07 hr. A depression off north-west Ireland is moving north-eastwards. Winds will be south to south-west and rain will occur generally, although in southern England amounts will not be large. Further outlook: Unsettled.

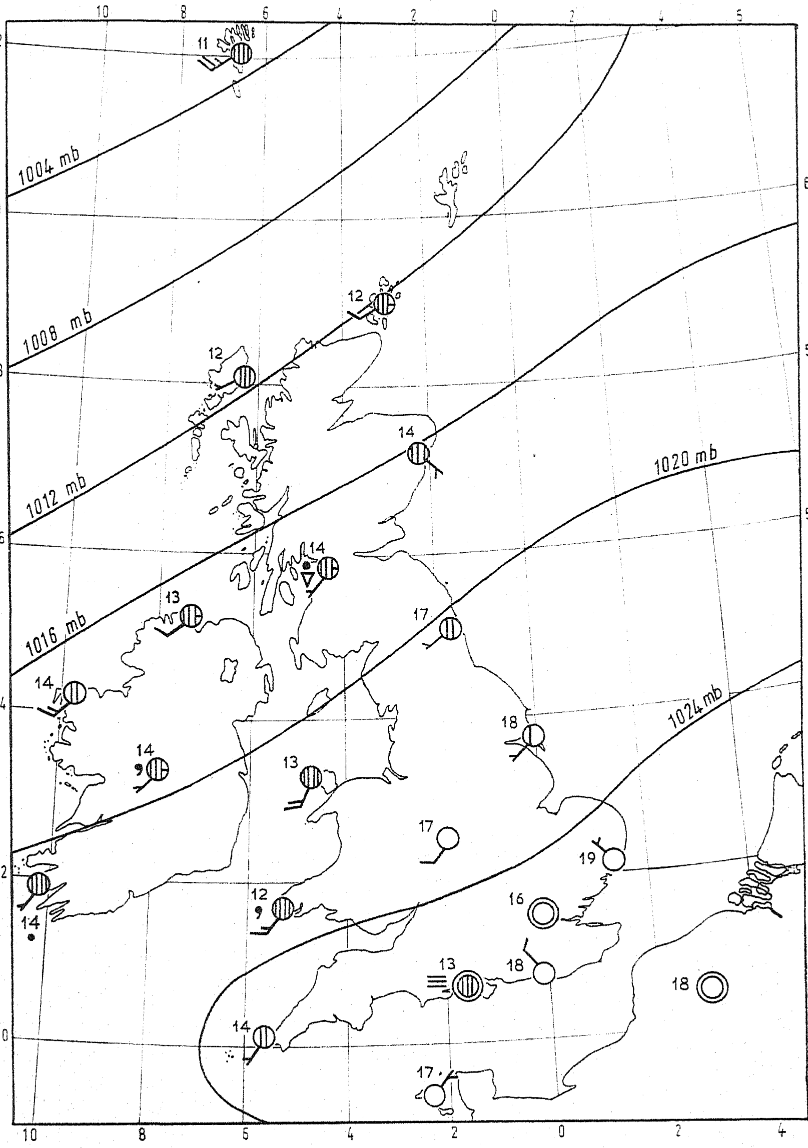


Fig. 123.

12th July, 07 hr. A belt of high pressure extends from beyond the Azores across France to Central Europe. Over most of England mainly fine and very warm weather will continue while in the northern and western parts of the British Isles there will be cloudy periods with occasional local drizzle. Further outlook: Similar.

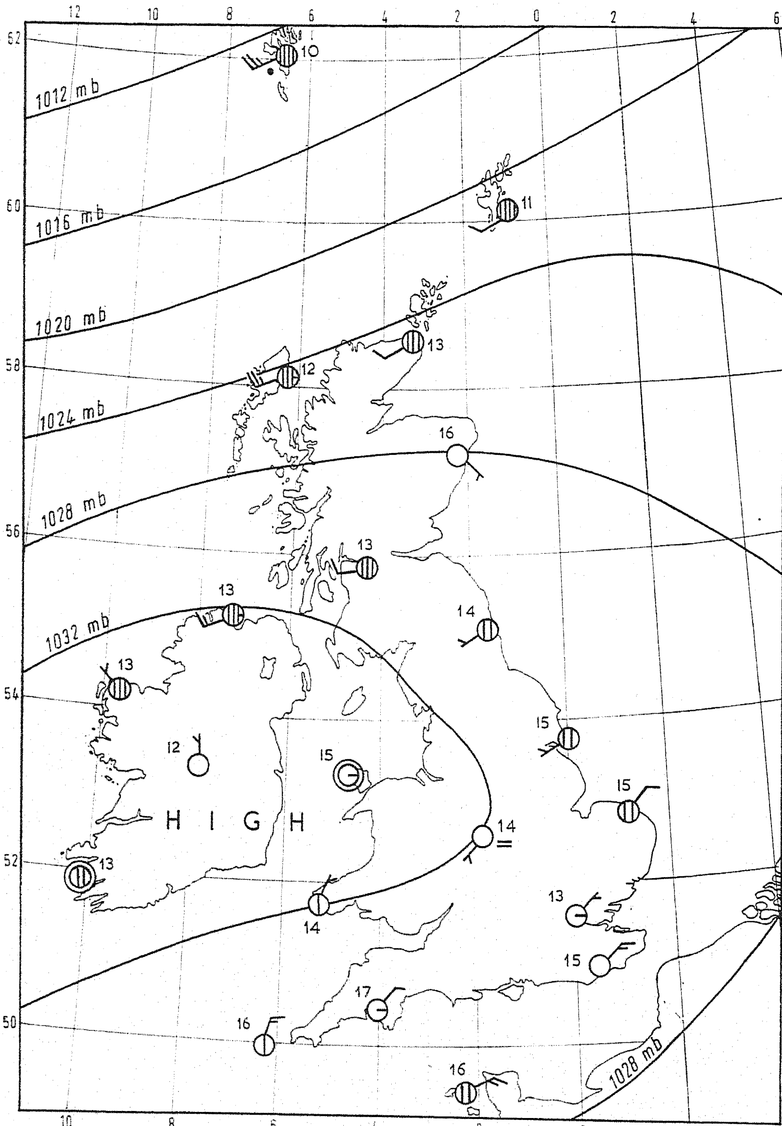


Fig. 124.

17th July, 07 hr. A large anticyclone covers Ireland, England, and the southern North Sea. Fine weather will continue over most of the British Isles and probably last for four or five days. Temperatures will tend to rise again.

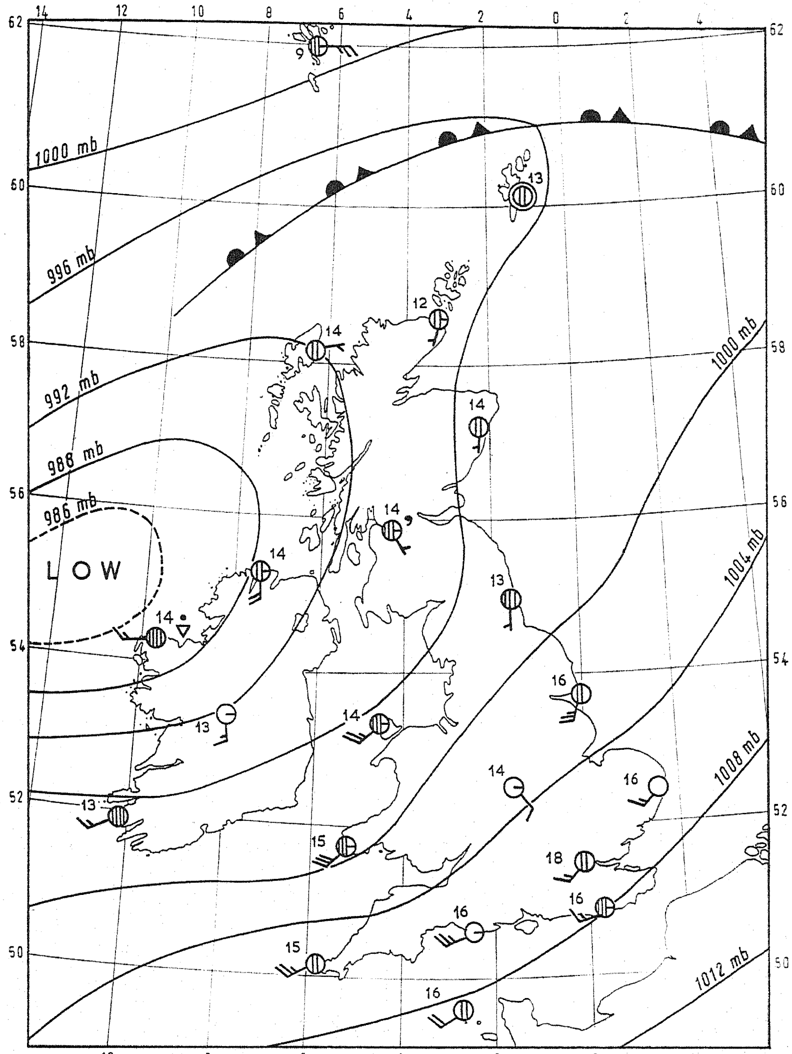


Fig. 125.

13th August, 07 hr. A deep depression off north-west Ireland remains stationary. Weather will be showery with bright intervals and local thunder. Further outlook: Showery weather for three or four days.

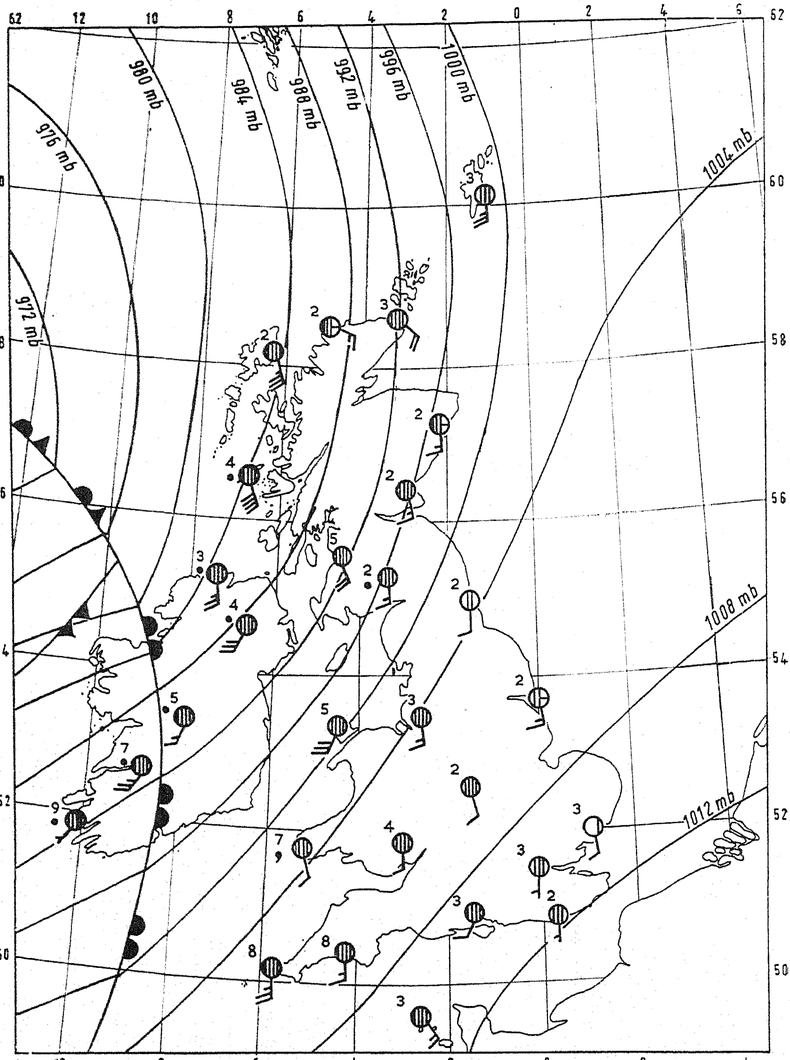


Fig. 126.

The great Storm of January 1953: at 1800 hrs on 30th January the warm sector associated with an intense depression centred between Scotland and Ireland was moving eastwards over western Ireland at about 40 mph, preceded by fresh to strong southerly winds. Note the higher temperatures at the two stations in the warm sector. The cloud belt in advance of the warm front is about 300 miles wide but the rain belt is comparatively narrow.

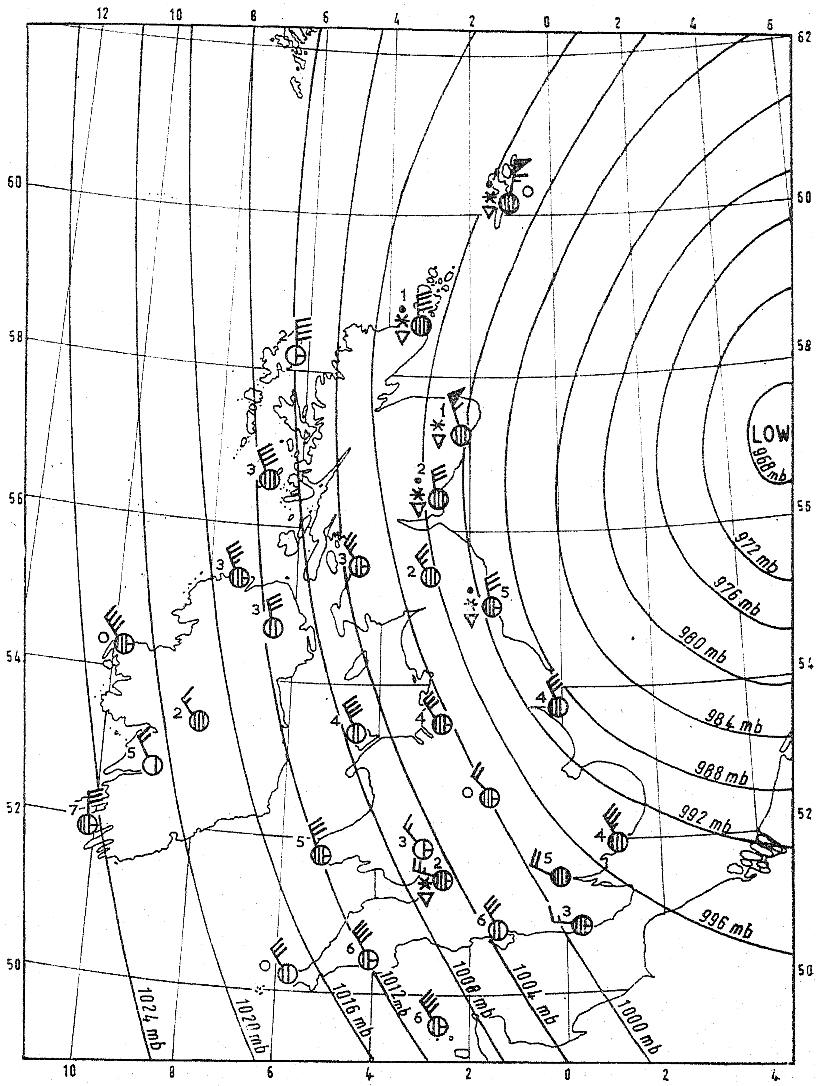


Fig. 127.

The great Storm of January 1953: By 1200 hr. on 31st January, the depression had moved south-eastwards and was now centred to the west of Denmark. The warm sector was completely occluded, and the front ran southwards across Denmark and then trailed south-westwards to the southern Bay of Biscay. The southerly winds over the British Isles have now been replaced by north-west to northerly gales. Lerwick in the Shetlands reported a mean wind of 67 *knots*. Spring tides in the southern North Sea, backed up by these winds, breached the coastal defences in many places and caused disastrous damage, from which some agricultural land has not even yet recovered.

CHAPTER XVI

CLIMATE MAPS

1. THE DIFFERENCE BETWEEN CLIMATE AND WEATHER MAPS

There is considerable difference between climate and weather maps. The weather map is essentially composite, most aspects of weather being shown on one map, whereas the climate map is more specialised, being, as a rule, used for only one main aspect.

Isobars are the most prominent features on the weather map, but no *lines* are used for temperature and rainfall. Temperatures are shown by numbers near the observing station, and are similar to spot heights on a contoured map. Rainfall and degree of cloudiness are indicated by symbols, and there are various symbols and letters for other aspects of weather (see p. 174). Thus, though a maximum of information is given on one weather map, it is not overcrowded as would be the case if isotherms and isohyets were used. Too few observations would be available for the latter, and quantity of rainfall is essentially a subject for averages, so on the weather map it is sufficient to indicate that rain was falling at individual stations.

Separate climate maps are generally used to show temperature, pressure, and rainfall conditions, using isotherms, isobars, and isohyets respectively (see p. 177). The isotherms are given on a separate map, because to include isobars with isotherms would lead to confusion, though sometimes study of certain isotherms may help understanding of the isobars. Low temperature is often a clue to high pressure, and high temperature to low pressure. It is better to study jointly the separate isotherm, isobar, and rainfall maps drawn on the same scale and projection than to crowd too much on one map. If maps drawn according to the same scale and the same projection are used, comparison and correlation of the various elements of climate will be easy. Arrows showing broadly the direction of the chief planetary winds can be combined with isobars, which obviously help to explain their particular movements over the earth's surface.

2. TYPES OF CLIMATE MAPS

Isobar, isotherm, and rainfall maps are constructed on the same principle as contour maps. The method is simple as long as observations from a sufficient number of stations are given. In rainfall maps, after the isohyets are drawn, shading or colour layering is often used between the lines. This is logical, as rainfall gives a concrete quantitative conception impossible in the case of temperature and pressure. The latter merely indicates the behaviour of mercury in a glass tube, whereas rainfall is a tangible thing. The colour, generally various tints of blue, indicates, according to the yearly average, that, say, between 60 and 80, or over 80, in. of rain have fallen in a specified region. The same thing could be read from the isohyets alone, but shading emphasises the difference, and the darker shading enables us to identify the districts of greatest rainfall.

Relief has considerable influence upon rainfall (see p. 205), and to understand the rainfall map easily it is desirable at the same time to refer to a relief map. Altitude affects temperature and pressure, so before temperature and pressure maps are made, the statistics are "reduced to sea level" in order that the resulting isotherms and isobars may be less complicated.

3. REDUCTION OF DATA TO SEA LEVEL EQUIVALENT

Reduction to sea level means that certain adjustments are made to cause the figures to be as nearly as possible what they would be if the places of observation were actually at sea level. Rate of fall of temperature with increase of height (known as **temperature gradient**), varies from time to time and in different places. The average of many observations has shown that in round figures 300 ft may represent the ascent producing a drop of 1° F. In some instances, *e.g.* in still air in certain Swiss valleys, there may be *increase* of temperature with altitude, known as **temperature inversion**, but such a local occurrence can be ignored in making general temperature maps.

Isotherms reduced to sea level give little information about actual temperature conditions, except on lowlands or relatively low uplands. In Tibet and the high lands of central Asia, which are 15,000 or more feet above sea level, they give quite a false impression, Tibet in July apparently having a higher temperature than the plains of Northern India, which is quite contrary to the real facts. However, if the isotherms were drawn from

unreduced temperatures, readings from many more stations would be necessary, especially in regions of diversified relief. Moreover, the map would be very difficult to construct and would closely resemble a relief map of the area, and would tend to mask the significance of other influences on the temperature of the region (see 4, 5, 6 below).

Isobars reduced to sea level may give a generalised impression not in accordance with actual conditions, especially in very high land. A station at sea level may show the reading of 30 in.; another station on a mountain not very far away may show, say, 25 in. If these readings were plotted directly on the chart, the result would be a big gradient necessitating very crowded isobars. To obtain comparable figures of value for forecasting weather conditions we must reduce readings to the same standard, and sea level equivalent gives such a standard.

4. INSOLATION AND TEMPERATURE

The sun is the chief factor in the control of climate, as it directly affects temperature, which is the most important element of climate, because of its influence on pressure, winds, and rainfall. The distribution of temperature over the surface of the globe, the diurnal and seasonal changes of temperature, are influenced by variations in the duration and intensity of sunshine. The duration and intensity of sunshine mainly depend upon (1) the angle at which the sun's rays strike the earth; (2) the length of day. Both (1) and (2) depend upon latitude, and if the sun alone were concerned, all places on the same parallel of latitude would experience the same temperature. Various factors, however, disturb this uniformity, *e.g.* distribution of land and water, mountain barriers, prevailing winds, and ocean currents.

The temperature of a place is represented by the difference between the quantity of heat received by the earth from the sun (**insolation**) and the amount lost by the earth through **radiation.**

The more direct the angle at which the sun's rays strike the earth, that is, the nearer it approaches a right angle, the greater will be the insolation. The angle varies according to the latitude of a place, and at the same place it may vary according to season. In England, at London, at the summer solstice (June 21st) the sun's rays strike the earth at an angle rather more than two-thirds = eight-twelfths of a right angle, while at the winter solstice

(December 21st) the angle is only quarter, *i.e.* three-twelfths of a right angle. Thus in June the insolation is much more than it is in December.

The longer the day, the greater the insolation, so that the length of the polar day in summer compensates for the acute angle at which the sun's rays strike the earth in polar regions.

5. BENDING OF ISOTHERMS

The distribution of land and water influences the course of isotherms. Owing to its higher specific heat, *i.e.* its slower heating and cooling capacity, water will be cooler than land in summer and warmer in winter. This accounts for the curious bending towards the equator and the poles of isotherms drawn on the sea. If they bend towards the pole, as off Western Europe in winter, we realise that the sea is then warmer than the land, for, as it were, a tongue of warmth over the sea is pushed towards the pole. Realisation of this fact is a great help in reading isotherm maps. Poleward bend of winter isotherms, especially 32° F., over the North Sea and adjoining Atlantic Ocean is also due to the warm Atlantic Drift which tends to heat the air blowing towards Europe as south-west winds.

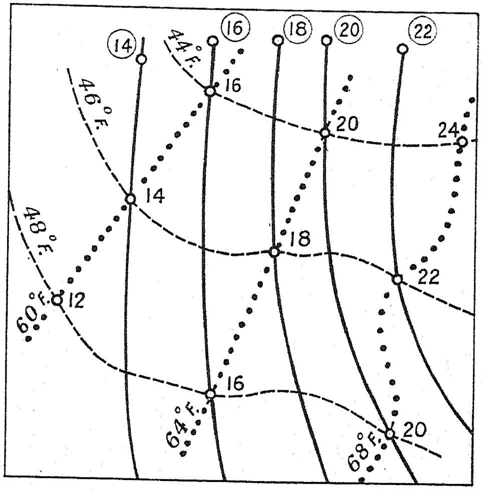


Fig. 128.
January isotherms - - - - July isotherms . . . .
Range lines ———

6. RANGE MAPS

Temperature maps are usually drawn with isotherms showing the mean of actual temperature observations for a single month or for the whole year, but there is another type of temperature map known as the **range map** (see Fig. 128).

Range is really the difference between the highest and the lowest temperatures ever experienced at a place. This is the absolute range of temperature, but it cannot easily be shown on a map, because such maximum and minimum temperatures vary from year to year. The average of such maxima and minima for a period of years is known as the mean annual **extreme** range, but a better way is to take the difference between the average temperatures for the hottest and coldest months. This difference is often called the mean annual range.

In a fairly large area the hottest or the coldest month may not be the same. The coldest month at one station may be January, at another February; at these stations the hottest months may be July and August respectively. However, the range can be ascertained by taking the difference between January and July in the one case and between February and August in the other. In such a case the range maps are made by plotting at each station the ranges thus ascertained, and then proceeding as for isotherms or contours.

There is another and more graphic way of constructing range maps. Take, drawn on the same scale, isotherm maps for the coldest and hottest month. On one of these maps trace the isotherms from the other. Where one isotherm (coldest month) cuts another (hottest month) find the difference between their values, and insert this difference, like a spot height, at the point of intersection. Such differences are range values, and the range-lines can then be drawn like contours. No range-line must cross an isotherm except at intersections, but range-lines must cross both isotherms at the intersection. Draw the cold month isotherms in pencil, those of the hot month with a lighter black ink line. Range lines can be drawn with coloured pencil or red ink, and will thus stand out boldly.

7. RELATION BETWEEN ALTITUDE AND PRESSURE

Barometric readings denoting pressure of the atmosphere are always lower on the top than at the bottom of a mountain and this is because both (1) the depth of air above you, and (2) the density of the air, is less at the higher station. Near sea level a layer of air 9 ft thick is approximately equal in weight to a layer of mercury $\frac{1}{100}$ in. thick. Hence for every 9 ft the barometer is raised, the reading will be $\frac{1}{100}$ in. less. If air were at all times and in every place of the same density, the height of any mountain

would be obtained by reading the barometer at the bottom and at the top, reckoning the mean as hundredths of an inch and multiplying by 9. However, the density of air is affected by both pressure and temperature. Tables are given containing what are known as "factors" for certain mean pressures and mean temperatures, and these factors are used in the way that 9 would be used, as suggested above, if air were a constant density. For instance, if the mean barometric pressure is 29 in., the factor for 30° F. is 9; for 40° F., 9·2; for 50° F., 9·4; if 30 in., the factor is 8·7, 8·9, 9·1 for the same temperatures.

The height is found by reading the barometric pressure, say, 30 in. at the foot of a hill with temperature 45° F., and 28 in. at the top with temperature 35° F., representing a difference of 200 hundredths of an inch. This gives a mean of 29 in. pressure and 40° F. temperature. Therefore the factor is 9·2 and the height is $9{\cdot}2 \times 200 = 1{,}840$ ft. Approximately 900 ft of ascent will correspond to a drop of one inch of mercury, so to reduce to sea level, one inch for every 900 ft of height is added to actual barometric readings.

8. CAUSE AND TYPES OF RAIN—RAINFALL MAPS

CAUSE OF RAIN.—Air at any given temperature and pressure can contain a definite amount of water vapour uncondensed and invisible. When it contains the maximum amount it is said to be **saturated**, and the temperature at which saturation is reached is called **dew point**. If air is cooled beyond dew point some of the water vapour is condensed as mist or cloud, and if the cooling is continued, rain falls. Hence cooling of air is the primary cause of rain. Expansion on rising is the most usual cause of cooling. There are various causes of rising and they differentiate certain types of rain, namely:

RELIEF RAIN.—This is caused when air blowing from a relatively warm sea comes in contact with coastal mountains, is forced upwards, and so cooled beyond dew point. The prevailing westerly winds bring heavy relief rain to the coastal districts of the British Isles, and of countries like Norway, where there is high land along the coasts.

CYCLONIC RAIN.—This is due to upward movement of air in connection with low-pressure systems or cyclones (see Chapter XV, Polar Front Theory).

CONVECTIONAL RAIN.—Land is heated by the sun, and when insolation (see p. 202) is great, the air becomes very warm and rises in the form of

convection currents. It thus expands and cools, thus producing rain. Within the tropics convection plays a big part in causing heavy downpours; the summer rain of the steppes and prairies is also largely of this type.

RAINFALL MAPS.—Usually in atlases and textbooks there is a map known as the *mean annual rainfall map*. It is based on averages for the whole year extending through a series of years. Such a map gives a very fair idea of the average quantity of rain in various districts, and on a world map, the isohyet of 10 in. corresponds very closely with the dry deserts.

However, the geographer studying crop distribution or tree growth must know not merely how much rain falls in different parts of his regions, but also when it falls. That is, he must know whether it is largely seasonal, as in monsoon or Mediterranean lands, or whether it is evenly distributed throughout the year. Hence, something more than the mean annual map is necessary. A map for each month is helpful, as well as one for each season, and certainly one for both hot and cold seasons. Some maps show the total quantity of rainfall for each season, others the season's amount as a percentage of the year's fall.

Rainfall to a very great degree depends on wind direction and relief. Wind direction is associated with the world systems of high and low pressure, so that in some degree isobar maps assist us in differentiating regions of heavy or light rain, and of seasonal variations in rainfall. As a rule, low pressure areas are associated with heavy rainfall, whereas high pressure areas, where the descending air is dry, have much less rain.

In most good atlases there are climate maps adequate to illustrate points referred to in this chapter. Besides maps showing the amount of precipitation, *rainfall reliability maps*, temperature maps, and climatic regions maps are often given. Rainfall reliability maps show the percentage of years when the total rainfall reaches or exceeds the average and are particularly valuable when considering the possibility of marginal cultivation in semi-arid areas.

Temperature maps are usually plotted for average monthly temperatures, reduced to sea level, and those for January and July are most often selected as representing the most extreme months of the year. Maps for each month, those giving actual extremes, and ones showing the number of frost-free

days (or length of growing-season), are of even more value in assessing the climate of an area.

Because, in an atlas, it would be cumbersome to publish so many maps, both of temperature, rainfall, and rainfall-reliability, a compromise is often made by drawing maps of climatic regions. The world is divided into regions of broadly similar climate and maps showing the extent of each are given, often in bright colours. There is, of course, no sharp differentiation of climate at the boundary of each region, but provided this limitation is remembered, such maps are of great value to a geographer.

EXERCISE VIII

Weather and Climate Maps

Questions 1, 7, 8, 10, 11, are taken from papers of Ordinary Level standard, and 9, 15, 23, 24, 25 from papers of Advanced Level standard by kind permission of the Local Examinations Syndicate of the University of Cambridge.

Questions 18, 19, 20, 21, 22, are from papers set for the Intermediate Examinations in Arts and Science of the University of London and are reproduced by kind permission of the Senate.

1. Study the map (Fig. 129) which records, on a day in late November, the corrected barometric pressures at certain land stations and ship positions.
   (*a*) Join with neat lines all stations having the same pressures. What name is given to these lines?
   (*b*) Draw a graph to show the variations of pressure along the line *X-Y*.

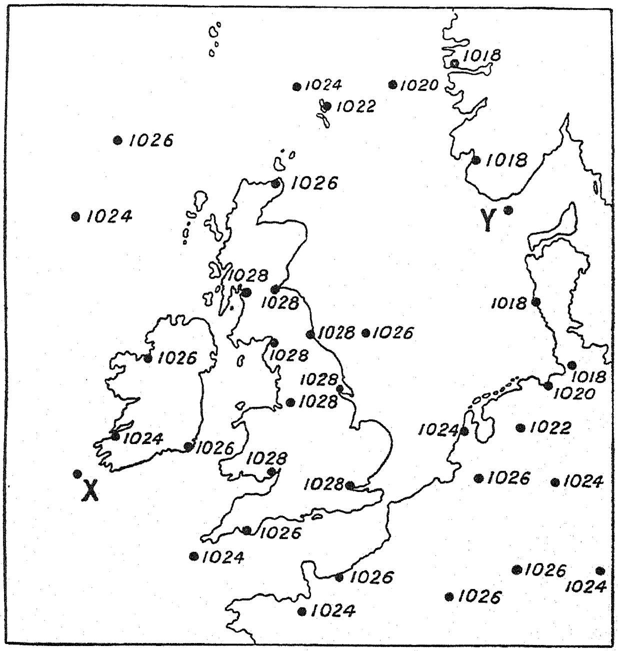


Fig. 129.

(c) Describe the distribution of pressure as indicated by the chart.

2. Explain why the maps (Figs. 115-127) given in Chapter XV would be of relatively little use in explaining the *climate* of the British Isles, though they illustrate several types of British *weather*.

3. Write a short account of the climate of the British Isles, and suggest types of diagrams or maps which might be used as illustrations.

4. In what way does an isotherm map or an isobar map (a) resemble, (b) differ from, a contoured map? What adjustment of data is usual before preparation of isotherm and isobar maps? Criticise such adjustment.

5. What data, not necessarily rainfall statistics, would you require for preparation of (a) a rainfall graph, (b) a rainfall map? How could the graph be made auxiliary to the map?

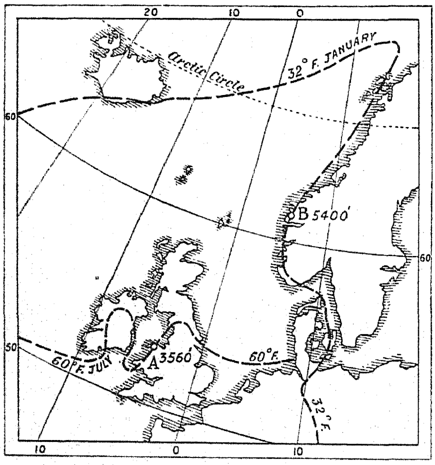


Fig. 130.

6. Analyse a typical weather map to show (a) what information can be derived from it, (b) what data would be required for its preparation.

7. On the map (Fig. 130) the isotherms are drawn for mean sea level temperatures in degrees Fahrenheit.

(a) On the map, shade the area in Ireland where the mean sea level temperature for January is highest and the area in England where it is lowest.

(b) State, to the nearest degree, the mean temperature at A in July and at B in January.
Explain how you obtain your answers.

(c) Explain the irregularities in the July isotherm 60° F. and in the January isotherm 32° F. respectively.

8. Give a general account of the weather which would be likely to occur under the conditions shown on the barometric charts given in Fig. 131. Indicate on the maps the directions of the winds.

9. Study the Weather Charts in Fig. 132 and notice the dates.

(a) What does *mb* stand for, and what is the value of 1 mb in inches?

(b) Show, by arrows in each chart, the direction of the wind on the north-east coast of Scotland and on the north-west coast of France.

(c) Describe the pressure changes which took place in the twenty-four hours.

(d) How would these changes have affected the weather in south-west England?

10. The map (Fig. 133) shows the corrected readings of the barometer, in millibars, at a number of observation points in Western Europe at 7 a.m. on a certain morning in March.

(a) Draw the isobars of 990, 995, 1,000, and 1,005 mb.

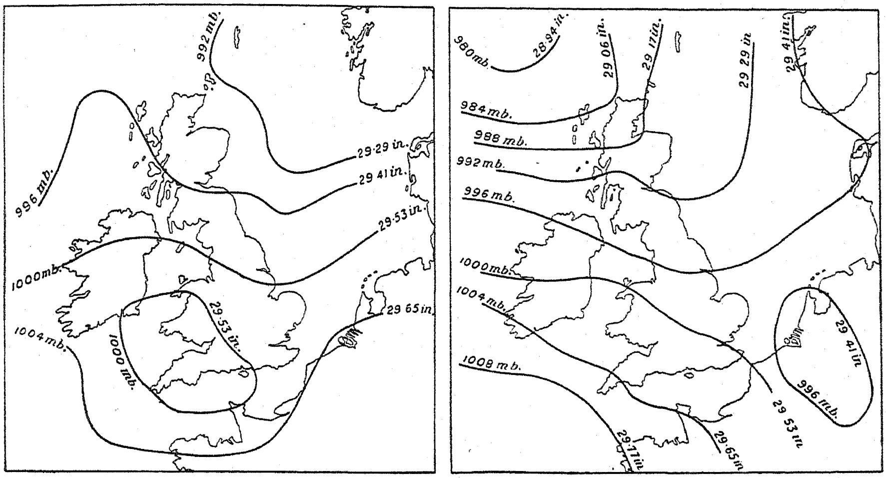


Fig. 131.

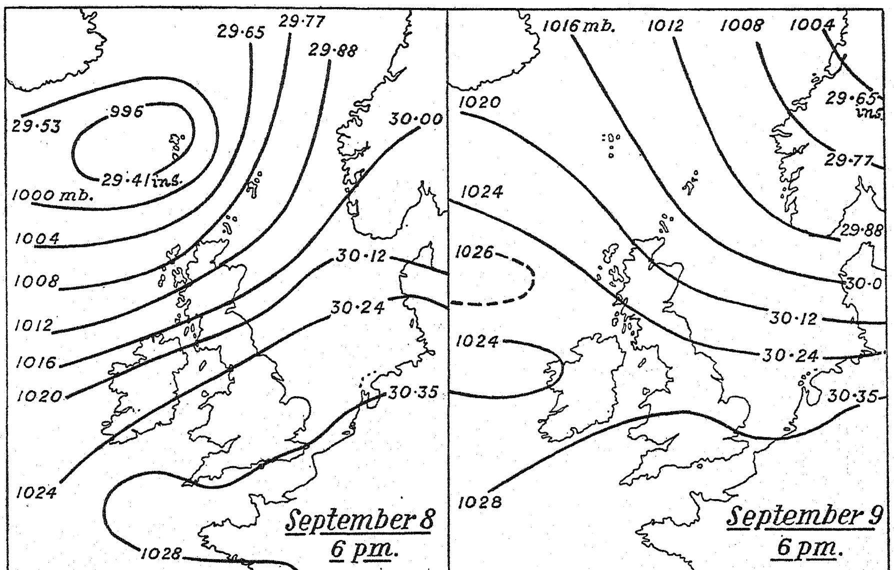


Fig. 132.

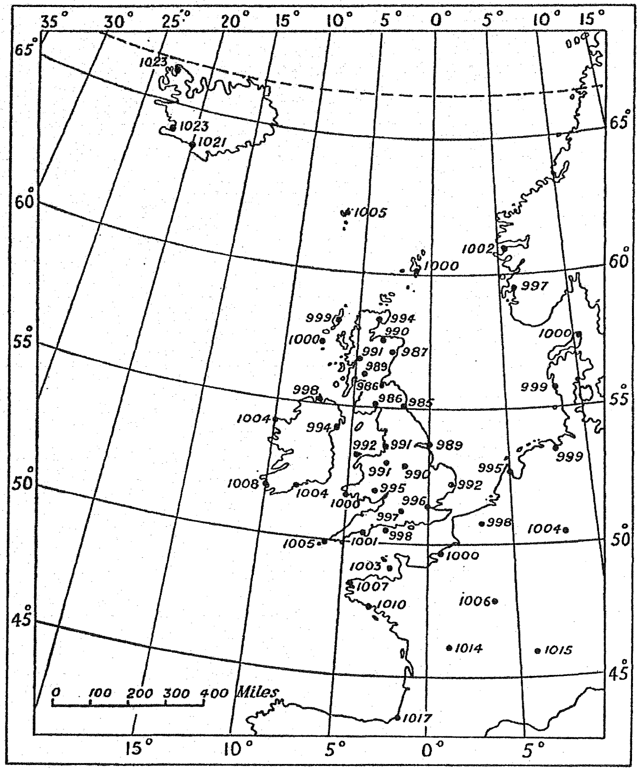


Fig. 133.

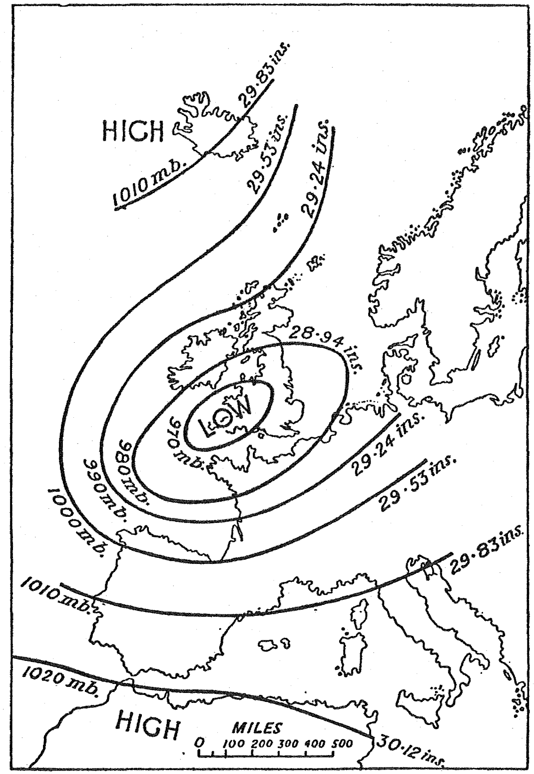


Fig. 134.

(*b*) Indicate by arrows the probable direction of the wind over western Ireland, southern England, Denmark, the Shetland Islands.

(*c*) How did you decide in which direction to point the arrows when answering (*b*)?

(*d*) Describe the distribution of pressure shown on the map.

11. The map (Fig. 134) shows the distribution of atmospheric pressure over Western Europe at 7 a.m. on a certain November day.

(*a*) Explain the significance of the words **High** and **Low** which are printed on the map.

(*b*) Indicate by arrows the probable direction of the wind over north-west Ireland, north Scotland, north coast of Spain, and Denmark.

(*c*) Shade lightly the areas where rain would probably fall during the day.

(*d*) How would the weather experienced during the day in south-east England differ from that experienced in southern Spain?

12. On the weather maps (Figs. 115-127) comment on the direction of the main air currents and compare them with the conventional planetary wind system of the area.

13. Write a short essay on the methods of weather forecasting, and note what unforeseen factors may possibly interfere with the forecast.

14. Compare any two maps showing the weather conditions associated with depressions and anticyclones (*a*) in winter, (*b*) in summer.

15. (*a*) On the chart provided (Fig. 135) name the different types of pressure systems and fronts shown.

(*b*) State, from the evidence on the map, the general weather conditions over western Ireland, central Scotland, and the Paris Basin.

(*c*) Give the maximum and minimum wind speed (in miles per hour) over the British Isles.

16. What weather system does each of the maps (Figs. 136, 137) typify? Describe the general conditions associated with such systems, and give reasons for any special features.

17. Reckon the gradient from *A* to *B* and *C* to *D* on diagram 138, and indicate the probable direction of the dominant winds in the area covered by the isobars.

18. On the accompanying weather map (Fig. 139) indicate by appropriate symbols:

(*a*) Wind speeds and directions at ten carefully selected stations.

(*b*) A warm and a cold front on the surface.

Give a general description of the weather in the area of the British Isles and Germany and shade the zone of probable rain.

19. Draw a general diagrammatic map showing by numbered isobars four distinct isobar configurations or "weather types" associated together. For any *one* such type describe the probable conditions of wind and weather.

20. Using the customary symbols, prepare a sketch synoptic weather chart to show a cold front and a line of occlusion over Britain in December. Write a short note on the temperature distribution.

21. Draw a weather map with isobars to show a wedge of high pressure separating a deep depression to the north-west from a weaker depression to the south-east. Insert indications of wind directions, cloudiness, and rainfall, using customary symbols.

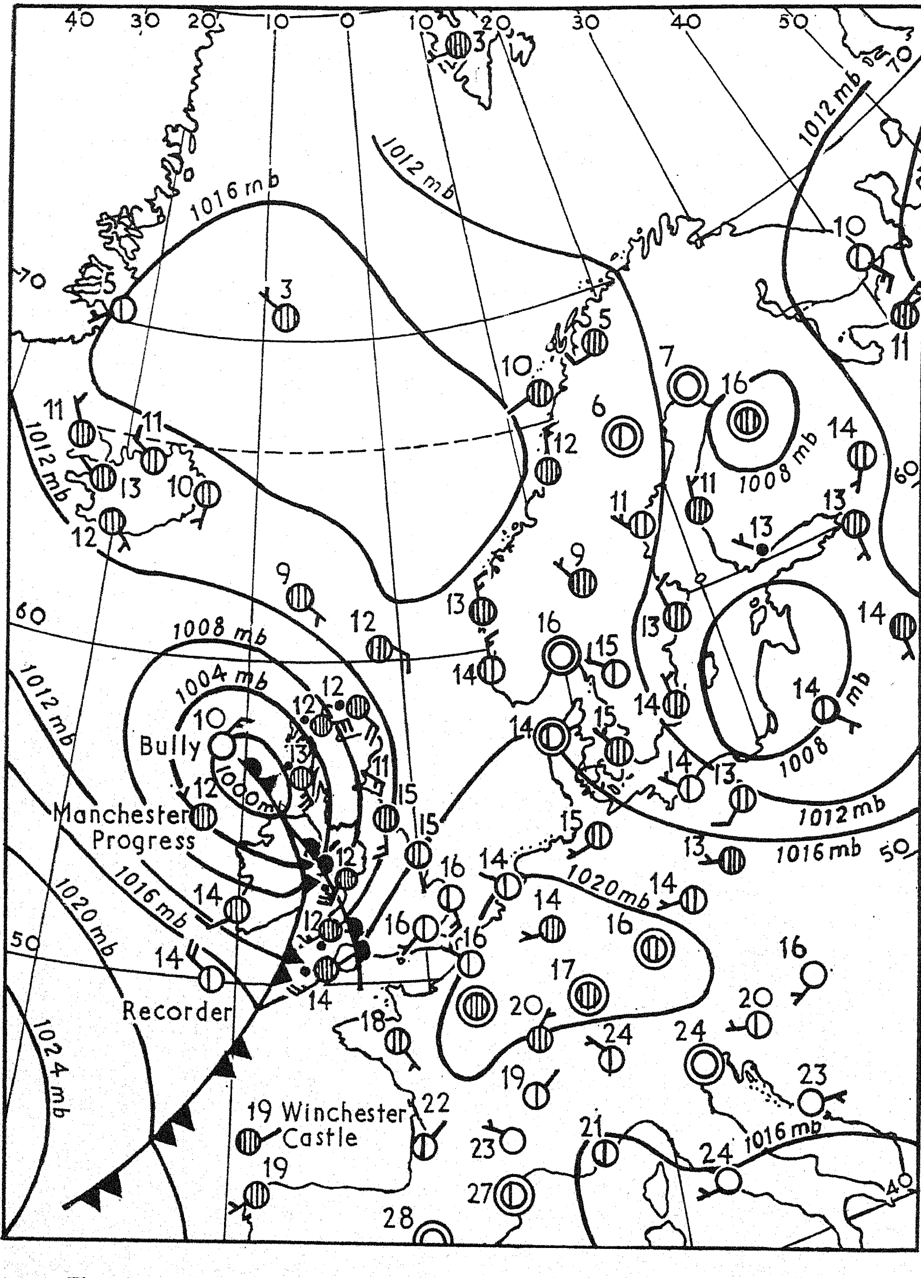


Fig. 135. THE EVENING OF THURSDAY, 12 SEPTEMBER 1946, AT 1800 HR. G.M.T.

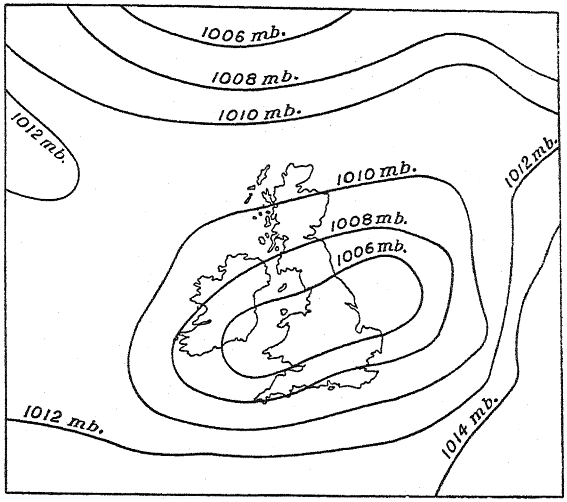


Fig. 136.

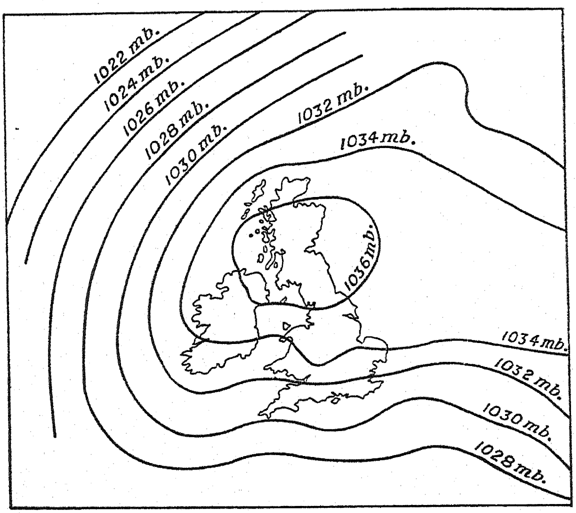


Fig. 137.

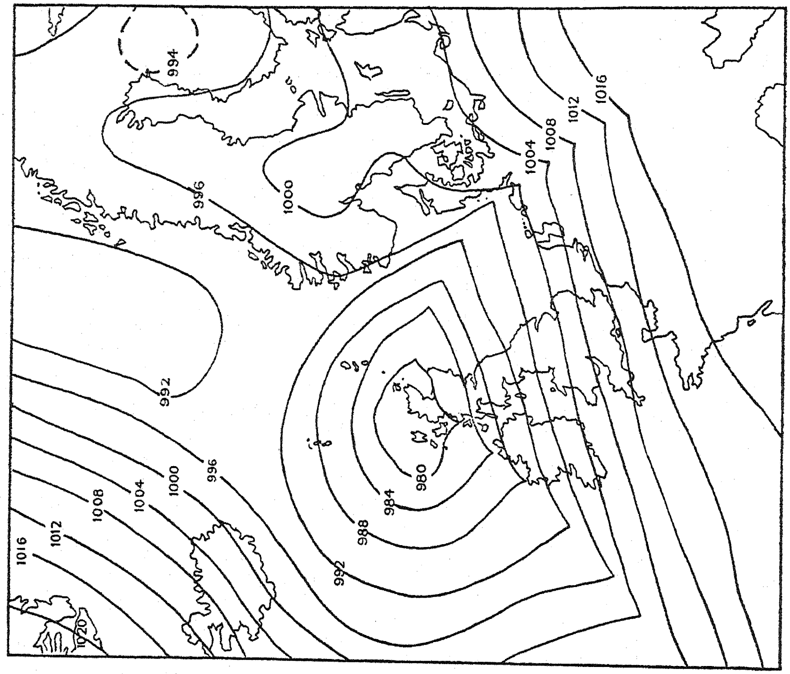


Fig. 139.

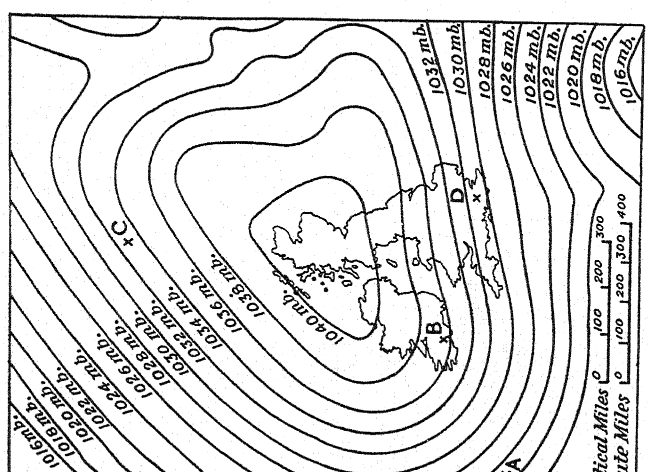


Fig. 138.

22. On an outline map, indicate a depression in an advanced stage of occlusion centred over the English Channel in spring. By means of appropriate conventional symbols, show the weather being experienced at eight stations within the system and briefly explain the chief features of the weather distribution shown.

23. Describe the probable pressure distributions associated with the following types of British weather—(i) a long spell of winter frost, (ii) strong south-westerly gales, (iii) an isolated fine interval during a period of rainy and unsettled weather. Illustrate your answer with simple weather maps.

24. Describe a possible distribution of pressure over the British Isles associated with each of the following types of weather—(*a*) a "heat-wave", (*b*) a "rainy spell", (*c*) "south-westerly gales". Draw simple synoptic charts to illustrate your answer.

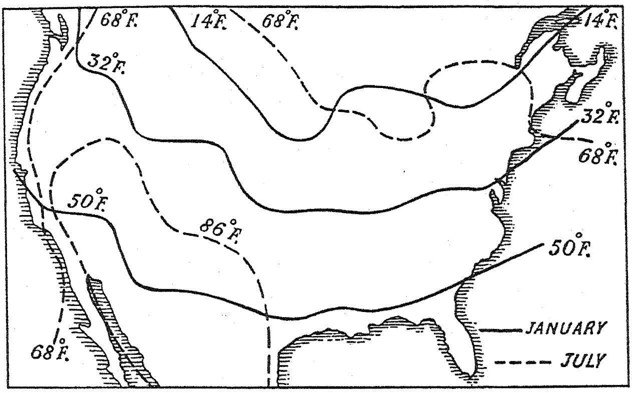


Fig. 140.

25. On the map given in Fig. 140, which shows isotherms for January and July, draw lines of equal annual range of temperature. Comment on any points of special interest.

PART III—MAP PROJECTIONS

CHAPTER XVII

MAP PROJECTIONS: I—LONGITUDE, LATITUDE, AND SCALE

1. GENERAL IDEAS ON MAP PROJECTION

A **Map Projection** is some method of representing on a sheet of paper the lines of latitude and longitude of the globe. Such lines are known as **parallels** of latitude and **meridians** of longitude. The earth is not a perfect sphere. It is relatively flat around the poles, and has been termed an "oblate spheroid of revolution", that is a figure produced by revolution of an ellipse around its shorter axis. The polar diameter is shorter than the equatorial diameter, but on a globe of, say, 5 ft diameter, the difference would amount to only about one-fifth of an inch. For practical purposes the geographer may regard the earth as a sphere. When he wishes to make a map on a flat sheet of paper, it is necessary to adopt some means of transferring to this paper the network of parallels and meridians in such a way that some approximation to the actual network of a globe is produced. Absolutely perfect representation is impossible, as can readily be seen if an attempt is made to flatten completely the skin of an orange (see also Fig. 144).

Though a globe is the only means of representing the earth's surface accurately, any globe large enough to show clearly the features of small but important countries would be both expensive to make and very cumbersome to use. Hence there is recourse to maps, which, though not mathematically perfect representations of the globe, can be made sufficiently accurate for all practical purposes if their limitations be understood and if the purpose of the map is borne in mind. The usefulness of a map for certain purposes depends upon the character of the projection used for the network of parallels and meridians. There are various ways of projecting these lines from the sphere to a sheet of paper. Each method of projection has its own advantages and disadvantages for specific purposes.

One projection may have both parallels and meridians as straight lines (**Mercator**, p. 244); another may have them both as curves (**Bonne**, p. 236); another may have curved meridians and straight parallels (**Mollweide**, p. 248, where, as in Bonne, one meridian is a straight line); another may have curved parallels and straight meridians (**Simple Conic**, p. 233). These and other projections will be described in subsequent pages, and their usefulness for particular purposes will be noted. They are mentioned here to show that parallels and meridians, which are curved on the globe, can be shown as curves or straight lines on certain projections.

The positions of points upon the globe are by convention defined by reference to parallels of latitude and meridians of longitude, and it is for this reason that such lines must be represented on any sheet of paper where we wish to draw a map. Such representations are termed **projections**, though few in current use are projections in the sense understood by a mathematician. Either of the words **graticule** or **network** has been suggested in lieu of projection, but the term **projection** still holds its own in textbooks and atlases.

Certain qualities are looked for in projections, but they cannot all be seen in the same projection, and those which show most fully the qualities best applicable to specific purposes are selected when maps are to be used for such purposes. The qualities which constitute a good projection centre round the degree to which it can preserve (1) the relative **area** and **scale**, and (2) the relative **shape and bearing** (see Fig. 144), compared with the globe. It is a further advantage if a projection is easy, both to draw and to compute. Many atlases, however, now use more complicated conventional projections (see p. 248) which, while preserving neither true area, nor true bearing, distort both size and shape to a minimum. Although their computation often necessitates the use of mathematical tables, these projections are more suitable for most general maps, than simpler projections, and those which, while representing accurately either area or bearing, distort the other very greatly at the edges of the map.

2. LONGITUDE, LATITUDE, AND SCALE

Before we can understand the practical methods underlying the construction of projections, it is necessary to grasp the meaning of longitude and latitude, and of scale as applied to the globe.

In the actual construction of projections, various methods are employed, the chief being (1) the so-called **graphical method,** which makes use of geometrical first principles (see, *e.g.*, p. 224); (2) what is known as the **trigonometrical method,** use being made of trigonometrical formulae to find the length of parallels, and the radii to construct them when they are circles (see, *e.g.*, p. 224). Sometimes recourse to mathematical tables is necessary for some of the more difficult projections. As a rule, an elementary knowledge of the first principles of trigonometry will suffice for many of the commoner projections. Some students prefer graphical methods, which give reasonably satisfactory results.

Examples are given of the construction of typical projections, but students desiring fuller treatment of the mathematics of map projections and detailed methods of construction are referred to standard books on the subject, such as those mentioned on p. 261.

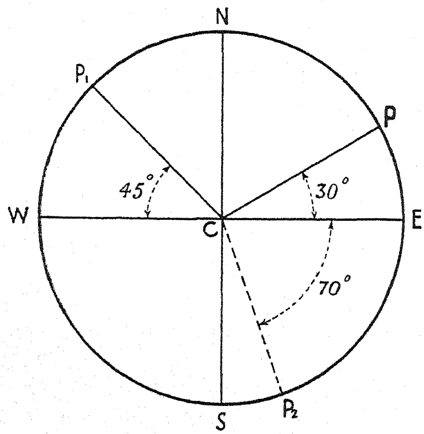


Fig. 141. To Illustrate the Meaning of Latitude.

Latitude.—Latitude is the angular distance north or south of the equator.

Let the Fig. 141 represent the plane of a section of the globe cut downwards (north to south) through its axis, *NS*. Let *C* be the centre of the earth, and *WE* the plane of the equator, and to aid graphic visualisation, imagine the earth to be a perfect sphere. The latitude of any place *P* on the surface of the globe is the angle made at *C*, the centre of the plane of the equator, by this plane *WE*, and the line joining *P* to the centre of the earth.

Thus the arc *PE* represents the latitude of *P* (30° N.), P_1W represents the latitude of P_1 (45° N.), P_2E represents the latitude of P_2 (70° S.).

The length of a degree of latitude is everywhere about 69 ml., though there are slight variations due to the fact that the earth is not a perfect sphere. Thus a degree of latitude is 68·7 ml. at the equator, 69·4 near the poles.

To find the length of any parallel of latitude of the globe. Consider Fig. 142. $WxEy$ and $W_1x_1E_1y_1$ represent the equator and another parallel of latitude, and each is the boundary (a circle) enclosing a plane surface. WC and W_1C_1 are radii of these circles respectively.

The latitude of the parallel $W_1x_1E_1y_1$ is the angle W_1CW (termed for convenience ϕ).

Now $WC = W_1C$ (radii of same circle, WW_1NES) and is represented by R, the radius of the globe.

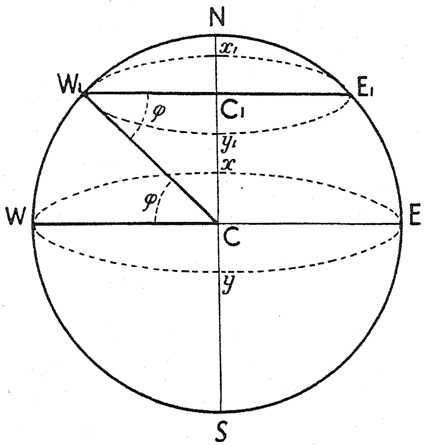


Fig. 142. LATITUDE.
To find the length of any parallel of latitude of the globe.

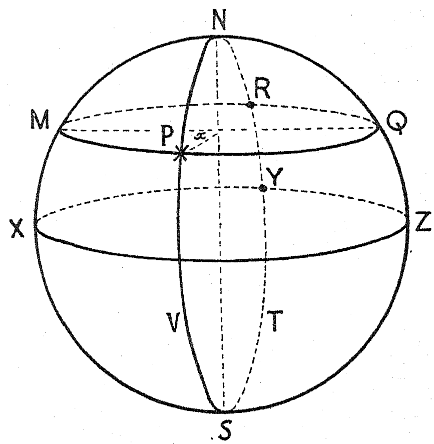


Fig. 143. THE MEANING OF LONGITUDE.

But the angle $E_1W_1C =$ the angle W_1CW (because W_1E_1 is parallel to WE) and thus the angle $E_1W_1C = \phi$.

Therefore $W_1C_1 = R \cos \phi$; but since W_1C_1 is the radius of the parallel $W_1x_1E_1y_1$ the length of the parallel $W_1x_1E_1y_1$ is $2\pi R \cos \phi$.

LONGITUDE.—A meridian of longitude is a line passing entirely round the globe and through the poles, and is always what is known as a **great circle.** A great circle passes entirely round the globe, and its plane passes through the centre of the globe.

Longitude is measurement east or west of a first or standard meridian, and is measured in degrees and their fractional parts (minutes or seconds).

A circle, or complete turn, represents 360°; therefore there will be 180° west and 180° east of the standard meridian. The longitude of a place is measured along the parallel of latitude on which the place is situated.

In Fig. 143, *XYZ* is a great circle, the equator; *MRQ* is a *small circle*, a parallel of latitude other than the equator; *NVST* is a great circle formed of the two meridians of longitude *NVS*, *NTS*; *NS* is the earth's axis.

If *NMX* is the first meridian (that of Greenwich), the longitude of any place *P* is measured by *MP*. This in degrees is equal to the angle x subtended by *MP* at the centre of the circle *MPQR*. This angle is equal to the angle between the planes *NMXS*, *NPVS*, that is the angle between the tangents at *N* to the arcs *NM*, *NP*. Hence, *the longitude of a place is equal to the angle at the pole between the first meridian and the meridian of the place.*

At the equator the length of a degree of longitude is $\frac{1}{360}$ of the equatorial circumference of the globe, or, in other words, $\frac{1}{360}$ of the equator, and is approximately 69 ml. At the poles, where all meridians meet, the length of a degree of longitude will be zero. We have already seen that the length of any parallel (or 360° of longitude, at a given latitude, ϕ) is equal to $2\pi R \cos \phi$. Thus the length of one degree of longitude at this latitude is $\frac{2\pi R \cos \phi}{360}$.

But $2\phi R$ is the length of the equator.

Therefore, the length of one degree of longitude at latitude $\phi = \cos \phi$ (the length of one degree of longitude at the equator)

$$= 69 \cos \phi \text{ ml. approx.}$$

The approximate length of a degree of longitude in miles for every 10° of latitude is as follows:

0° (equator)	69·2 ml.	50° lat.	44·6 ml.
10° lat.	68·1 „	60°	34·7 „
20°	65·0 „	70°	23·7 „
30°	60·0 „	80°	12·5 „
40°	53·1 „	90°	0·0 „

SCALE.—In the construction of projections, as with all maps, it is necessary to consider scale. In Chapter II the subject of map scales is treated in some detail, but for projections we must consider a few special applications.

Assume the earth to be a sphere with radius 3,960 ml., or approximately 250,000,000 in. Globes with a radius of 1 in. and 10 in. respectively would

be on a scale of 1 : 250 million and 1 : 25 million respectively. Scale has the significance of a ratio, and to say that a globe is on a scale of 1 : 250 million is to imply that in the model globe every length is theoretically one two-hundred-and-fifty millionth part of the original. On such a small scale it is impossible to show anything but the most general measurements of the globe.

On a scale of	1 : 125,000,000,	R, the radius of the globe,	$\simeq$ 2 in.
,, ,,	1 : 100,000,000	,, ,, ,,	$\simeq$ 2·5 in.
,, ,,	1 : 10,000,000	,, ,, ,,	$\simeq$ 25 in.

If this is understood, there will be no difficulty in working out scales for any projection, given the radius (R) of the sphere.

CHAPTER XVIII

MAP PROJECTIONS: II—GENERAL CLASSIFICATION; ZENITHALS, CONICALS, MODIFIED CONICALS

1. INTRODUCTORY

Sometimes we are told to imagine a globe, say, of glass, on which the parallels and meridians are represented by black lines, and to imagine at the centre of the globe a small electric light bulb, whose rays could be focused on some particular point of the globe. We are to suppose it is possible by means of the light to photograph on a sheet of sensitised paper, either flat, or rolled into the shape of a cone or cylinder, the parallels and meridians. The lines on such a photograph would constitute a true perspective projection.[1] Few of such projections would have any practical value, however, but the example serves to illustrate the three main classes of projections: (1) **Zenithal projections,** in which the parallels and meridians are projected on to a flat piece of paper (Fig. 144*b*), and which class includes the only practicable perspective projections; (2) **Conical projections,** in which they are represented on a cone of paper (Fig. 144*c*); (3) **Cylindrical projections,** in which they are represented on a cylinder (Fig. 144*d*). Any of these may be mathematically modified to improve their properties of retaining true shape or area, or to minimise distortions, and there is one further class of projections, (4) **Conventional projections,** which are devised entirely by mathematics.

2. ZENITHAL PROJECTIONS

Zenithals may be classed according to the position of the point where the paper touches the globe. If it does so (1) at either pole, it is termed a polar zenithal; if (2) at the equator, an equatorial zenithal; if (3) at some intermediate point, it is known as an oblique zenithal. These projections are sometimes termed *azimuthal*, since the azimuth, or bearing, to all points from the centre of the map is correct.

[1] This is only given as an illustration and is not a practical method of producing any projection.

Zenithal projections are most useful for polar regions and, as the polar cases are also the simplest to construct, only these will be considered here.[1]

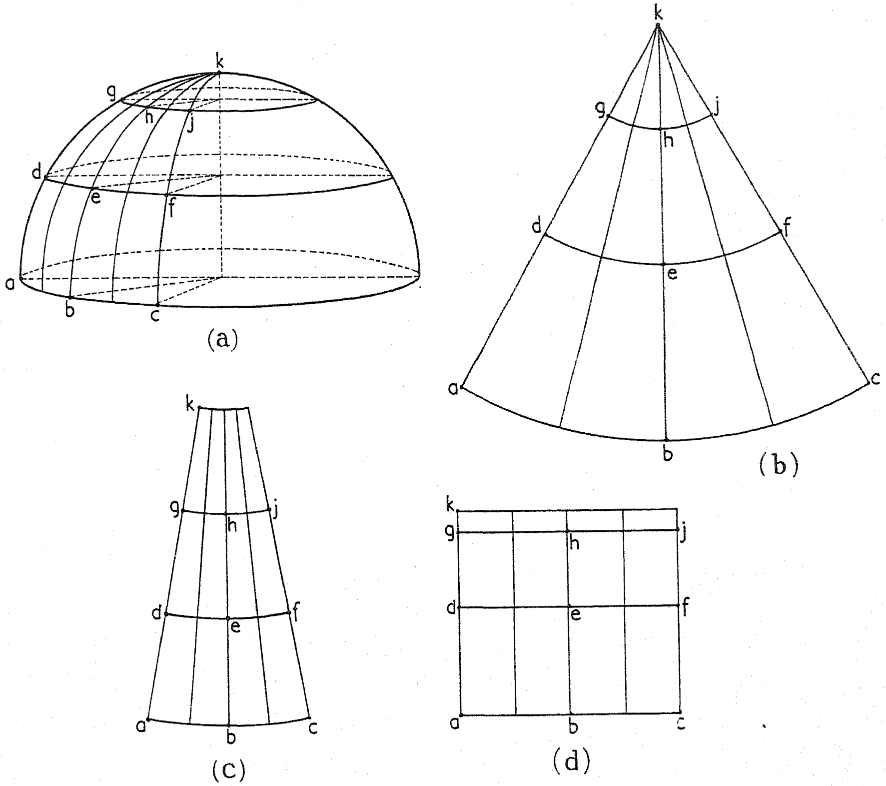


Fig. 144. To Show Part of the Globe and its Representation as a Plane, a Cone, and a Cylinder.

(*a*) Part of the globe with *abc* the Equator, *def* latitude 30° N., *ghj* latitude 60° N., *k* the North Pole. The meridians *kgda*, *kheb*, and *kjfc* are also 30° apart. (*b*) The same meridians and parallels as they would appear on a plane touching the globe at the North Pole (stereographic projection). (*c*) The same meridians and parallels as they would appear on a cone touching the globe at latitude 30° N. (single conical projection with one standard parallel). (*d*) The same meridians and parallels as they would appear on a cylinder touching the globe at the Equator (cylindrical equal-area projection).

[1] For treatment of the remaining cases, students are referred to *A Study of Map Projections* by J. A. Steers.

In them the pole is a point at the centre of the graticule and meridians are straight lines radiating from it, their correct angular distance apart (see Fig. 148).

1. THE GNOMONIC PROJECTION (polar case) is a true mathematical projection of meridians and parallels from the centre of the globe on to a plain sheet of paper, touching at the pole. In this projection, all great circles appear as straight lines and the projection is sometimes used for plotting great circle courses for aviators. The scale is nowhere correct, however,

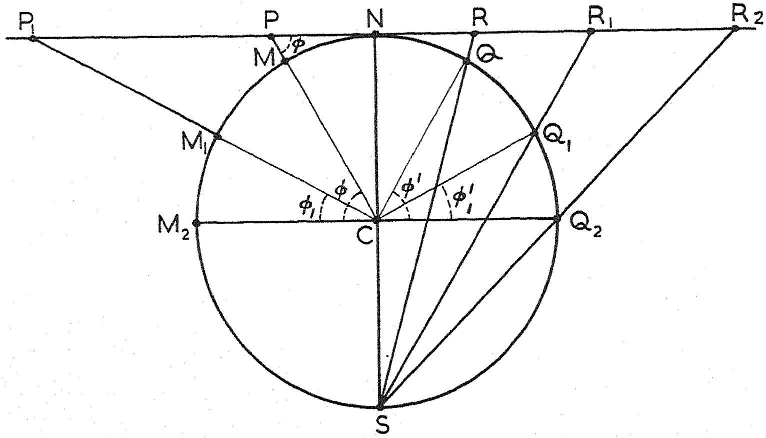


Fig. 145. TO OBTAIN RADII FOR THE CONSTRUCTION OF PARALLELS IN THE GNOMONIC AND STEREOGRAPHIC PROJECTIONS (POLAR CASES).

and distortion at the edges of the map is very great, and increases rapidly beyond 30° from the centre.

Construction.—On a sheet of plain paper, mark the pole as a point near the centre, and from it draw the meridians as radiating straight lines, their correct angular distance apart.

On a separate sheet of paper make a construction figure similar to the left-hand side of Fig. 145. In this figure the circle *SMNQ* represents the globe in section at the required scale for the projection, with *N*, *S*, and *C*, the north and south poles and centre, respectively, and *M*, M_1, etc., points of latitude ϕ, ϕ_1, etc. NPP_1 is the plane of projection, touching the globe at *N*.

Produce CM to meet NPP_1 in P, CM_1 to meet NPP_1 in P_1, etc.

Then NP, NP_1, etc., are the radii for construction of parallels latitude ϕ, ϕ_1, etc.

It is clear from the figure (since $CM_2 \parallel NP_1$) that the equator cannot be drawn on this projection.

Return to the network of meridians already drawn, and with the pole as centre and radii NP, NP_1, etc., draw in the parallels.

Trigonometrical Method.—For the meridians proceed as above.

Then in $\triangle\, NCP$, $NC = R$ (the radius of the globe),

$$\angle\, CPN = \phi;$$

$$\therefore\; NP = R \cot \phi.$$

Similarly, $NP_1 = R \cot \phi_1$, etc.

From these formulae[1] the radii for construction of the parallels can be calculated.

2. THE STEREOGRAPHIC PROJECTION (polar case).—Like the gnomonic, this projection is a true perspective projection. The point of projection, this time, is at the opposite end of the diameter to the point at which the globe touches the plane of projection. Scale is nowhere correct, but exaggeration is less than in the gnomonic projection, and great circles are no longer represented by straight lines. The projection is orthomorphic, that is to say preserves shapes; although it exaggerates their area.

Construction.—On a sheet of plain paper, mark the pole as a point near the centre, and from it draw the meridians as radiating straight lines, their correct angular distance apart.

On a separate sheet of paper, make a construction figure similar to the right-hand side of Fig. 145. In this figure, the circle $SMNQ$ represents the globe in section, at the required scale for the projection, with N, S, and C, the north and south poles and centre, respectively, and Q, Q_1, etc., points of latitude ϕ', ϕ_1', etc. Q_2 is a point on the equator. NRR_1 is the plane of projection, touching the globe at N.

Produce SQ to meet NRR_1 in R, SQ_1 to meet NRR_1 in R_1, and SQ_2 to meet NRR_1 in R_2, etc.

[1] A table showing trigonometrical ratios for use with the formulae is given on p. 230.

Then NR, NR_1, etc., are the radii for construction of parallels latitude ϕ', ϕ_1', and NR_2 is the radius for the equator.

Return to the network of meridians already drawn, and with the pole as centre and radii NR, NR_1, etc., draw in the parallels.

Trigonometrical Method.—For the meridians proceed as above.

Then $\angle NSQ$ (at the circumference) $= \frac{1}{2} \angle NC$ (at the centre) (opposite arc NQ);

$$\therefore \angle NSQ = \tfrac{1}{2}(90° - \phi') \; (\angle NCQ_2 \text{ is a right angle}).$$

But in $\triangle NSR$, $NS = 2R$;

$$\therefore NR = 2R \tan \tfrac{1}{2}(90° - \phi').$$

Similarly, $NR_1 = 2R \tan \frac{1}{2}(90° - \phi_1')$, etc.

From these formulae the radii for construction of the parallels can be calculated.

3. THE ORTHOGRAPHIC PROJECTION.—This is the only remaining perspective projection to be used at all, and is not very common, except in astronomical projections of the heavens. The point of projection is at infinity and parallels become very close together at the edges of the map. The projection is neither equal area, nor orthomorphic.

Construction.—On a sheet of plain paper, mark the pole as a point near the centre, and from it draw the meridians as radiating straight lines, their correct angular distance apart.

On a separate sheet of paper, make a construction figure similar to the left-hand side of Fig. 146. In this figure, the circle $SMNQ$ represents the globe in section at the required scale for the projection, with N, S, and C, the north and south poles and centre, respectively, and M, M_1, etc., points of latitude ϕ, ϕ_1, etc. M_2 is a point on the equator. NPP_1 is the plane of projection, touching the globe at N.

Draw MP, M_1P_1, and M_2P_2, etc., parallel with SCN.

Then NP, NP_1, etc., are the radii for construction of parallels latitude ϕ, ϕ_1, etc., and NP_2 is the radius for the equator.

Return to the network of meridians already drawn and with the pole as centre and radii NP, NP_1, etc., draw in the parallels.

Trigonometrical Method.—For the meridians proceed as above.

Then in $\triangle$ CMX, $CM = R$ and $\angle$ CXM is a right angle;

$$\therefore\ CX = R\cos\phi.$$

But since $NC \parallel XP$, $NP = CX = R\cos\phi$.

Similarly, $NP_1 = R\cos\phi_1$, etc.

From these formulae, the radii for the construction of the parallels can be calculated.

4. THE ZENITHAL EQUAL AREA PROJECTION.—In this projection the parallels are spaced so that each contains the same area on the flat paper as the curved area it contains on the globe. The scale is not correct, however, exaggeration along the parallels being compensated by diminution along the meridians. Shapes are badly distorted near the edge of the map, but the projection is suitable for distribution maps of high latitudes and, in its oblique case, for other areas as well.

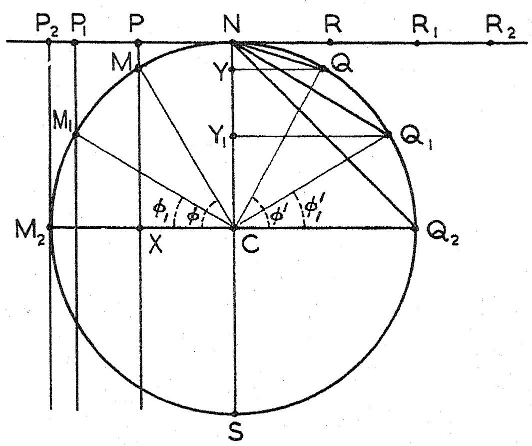


Fig. 146. TO OBTAIN RADII FOR THE CONSTRUCTION OF PARALLELS IN THE ORTHOGRAPHIC AND ZENITHAL EQUAL AREA PROJECTIONS (POLAR CASES).

Construction.—On a sheet of plain paper, mark the pole as a point near the centre, and from it draw the meridians as radiating straight lines, their correct angular distance apart.

On a separate sheet of paper make a construction figure similar to the right-hand side of Fig. 146. In this figure the circle $SMNQ$ represents the globe in section at the required scale for the projection, with N, S, and C, the north and south poles and centre, respectively, and Q, Q_1, etc., points of latitude ϕ', ϕ_1', etc. NRR_1 has been drawn as the plane of projection, but since this is not a true mathematical projection, it is not necessary for it to touch the globe at all.

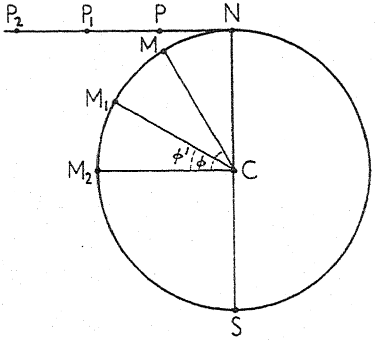


Fig. 147. To Show the Radii used for Construction of the Parallels in the Zenithal Equidistant Projection (Polar Case).

The area enclosed on the surface of the globe within the small circle latitude ϕ' (radius YQ) is equal to the area enclosed within a circle described with a radius equal to the chord NQ.[1]

Thus NR, NR_1, etc., the radii for construction of parallels ϕ', ϕ_1', etc., are respectively equal to NQ, NQ_1, etc., which can be measured from the figure.

Return to the network of meridians already drawn, and with the pole as centre and radii NR $(= NQ)$, NR_1 $(= NQ_1)$, etc., draw in the parallels.

Trigonometrical Method.—For the meridians proceed as above.

Then NRR_1 is tangent to the globe at N;

$\therefore$ $\angle RNQ$ (between tangent and chord) $= \frac{1}{2} \angle NCQ$ (angle subtended at centre).

$$\angle CNQ = 90° - \angle RNQ = 90° - \tfrac{1}{2} \angle NCQ = 90° - \tfrac{1}{2}(90° - \phi') = \tfrac{1}{2}(90° + \phi').$$

But in $\triangle NCQ$, $$\frac{CQ}{\sin \angle CNQ} = \frac{NQ}{\sin \angle NCQ};$$

$$\therefore NQ = \frac{CQ \sin \angle NCQ}{\sin \angle CNQ} = \frac{R \sin (90° - \phi')}{\sin \frac{1}{2}(90° + \phi')} = \frac{R \cos \phi'}{\sin \frac{1}{2}(90° + \phi')}.$$

Similarly, $$NQ_1 = \frac{R \cos \phi_1'}{\sin \frac{1}{2}(90° + \phi_1')}, \text{ etc.}$$

The radii for the construction of the parallels can thus be calculated.

5. The Zenithal Equidistant Projection.—In this projection, the parallels are spaced their correct distance apart. Meridian scale is thus kept true, but parallel scale is exaggerated away from the centre of the map, and neither equal area, nor orthomorphism results.

[1] For a proof of this statement, students are referred to mathematical textbooks, as it is beyond the scope of the present volume.

Construction.—On a sheet of plain paper, mark the pole as a point near the centre, and from it draw the meridians as radiating straight lines, their correct angular distance apart.

Now see Fig. 147 in which the circle M_2MNS represents the globe in section at the required scale for the projection, with N, S, and C, the north and south poles and centre, respectively, and M, M_1, etc., points of latitude ϕ, ϕ', etc. M_2 is a point on the equator. NPP_1 has been drawn as the plane of the projection, but since this is not a true mathematical projection, it is not necessary for it to touch the globe at all.

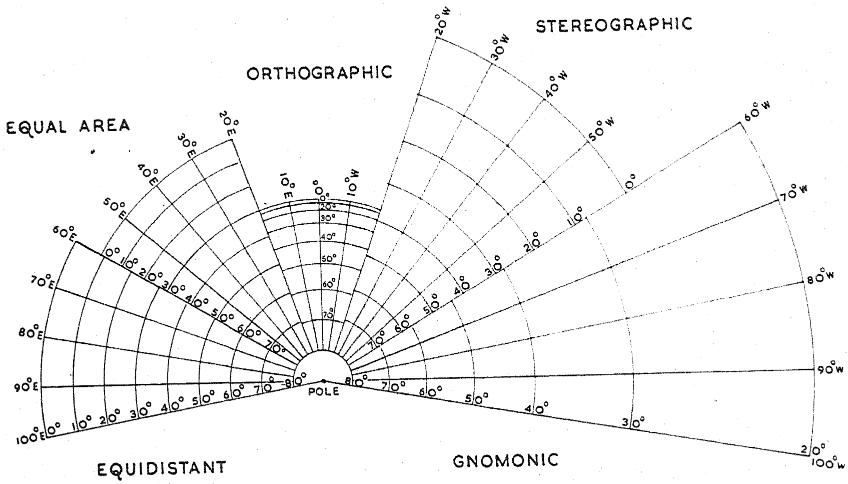


Fig 148. THE ZENITHAL PROJECTIONS.

There is no graphical method for construction of this projection, because it is not possible to measure the curved distances MN, M_1N, etc., from the figure. The calculation is quite simple, however, as follows:

The curved distance MN : the circumference of the globe $(= 2\pi R)$

$$= \angle MCN : 360°;$$

$$\therefore \quad MN = 2\pi R \times \frac{\angle MCN}{360°} = \frac{2\pi R\,(90° - \phi)}{360°}.$$

Similarly, $$M_1N = \frac{2\pi R\,(90° - \phi')}{360°}.$$

From these formulae the radii for construction of the parallels can be calculated. Return to the network of meridians already drawn, and with the pole as centre, and the radii thus calculated, draw in the parallels.

Some trigonometrical ratios for use with formulae for map projections are now given.

	sin	cos	tan	cot	cosec	sec
80°	0·9848	0·1736	5·6713	0·1763	1·0154	5·7588
70°	0·9397	0·3420	2·7475	0·3640	1·0642	2·9238
60°	0·8660	0·5000	1·7321	0·5774	1·1547	2·0000
50°	0·7660	0·6428	1·1918	0·8391	1·3054	1·5557
40°	0·6428	0·7660	0·8391	1·1918	1·5557	1·3054
30°	0·5000	0·8660	0·5774	1·7321	2·0000	1·1547
20°	0·3420	0·9397	0·3640	2·7475	2·9238	1·0642
10°	0·1736	0·9848	0·1763	5·6713	5·7588	1·0154

3. CONICAL PROJECTIONS

The most useful case of a conical projection is that in which the apex of the cone lies on the produced axis of the globe. The cone then touches the globe along a line of latitude which is known as the **standard parallel.** The scale along the standard parallel is always correct.

No true perspective conical projection is of any practical value, but simple conical projections, devised, in part, conventionally, are relatively easy to construct.

1. THE SIMPLE CONICAL PROJECTION WITH ONE STANDARD PARALLEL.—(See Fig. 149.) In this projection, as its name implies, the cone OPP_1 is imagined to touch the globe along a single standard parallel S_1S_2. When the cone is spread out, this parallel appears as an arc of a circle (radius OS_1), and its correct length. The meridians are drawn in as radiating straight lines OP, OM_1, OM_2, OP_1, etc., passing through the apex of the cone and their correct positions on the standard parallel (see also Fig. 150). Thus far the projection is a true perspective projection, but the spacing of the remaining parallels is obtained by making them arcs, concentric with the standard parallel and their correct distance apart, and not by calculating what their positions would be in a true perspective projection.

The projection is neither equal area, nor orthomorphic. Meridians are straight lines, however, and the meridian scale is everywhere correct, although

the parallel scale is correct only along the standard parallel. Meridians and parallels cross at right angles, moreover, and the distortion is not great in the centre of the map, and especially near the standard parallel.

The projection is suitable for the representation of areas with a considerable range of longitude, but little range of latitude, as, for example, in a map of the Trans-Siberian Railway, the central parallel on the map being made the standard parallel. It is also suitable for atlas maps of small

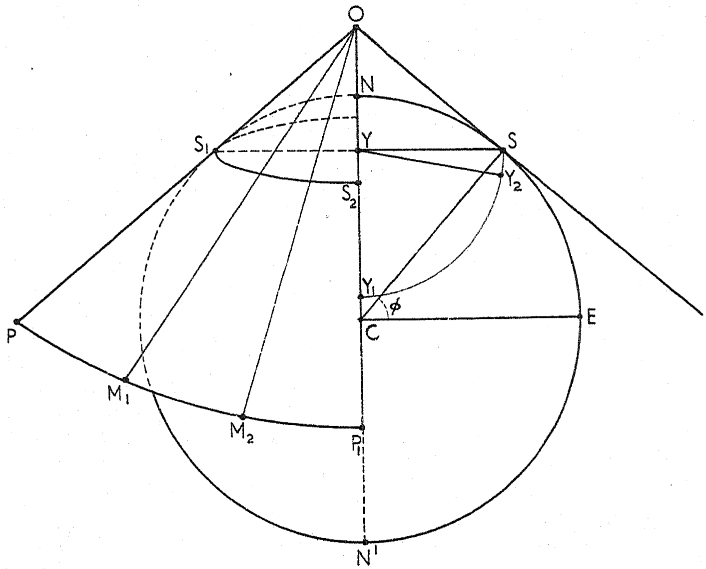


Fig. 149. THE SIMPLE CONICAL PROJECTIONS WITH ONE STANDARD PARALLEL.
On the left, the globe with part of the cone in place. On the right, a section through the globe and touching cone to show the method of construction of the projection.

countries such as the Netherlands, its great advantage being its extreme simplicity of construction. It is not often used for such maps, however, the simple conical projection with two standard parallels (see p. 233), or Bonne's projection (see p. 236), being preferred.

Construction.—Make a construction figure, similar to the right-hand side of Fig. 149. In this figure, the semicircle *NSEN′* represents half of the globe in section at the required scale for the projection, *N*, *N′*, and *C*

being the north and south poles and centre, respectively. E is a point on the equator, and S a point on the standard parallel, latitude ϕ (here, 50°).

OS is a tangent to the globe at S and therefore represents a section through the cone of projection with apex at O, on $N'N$ produced, and touching the globe at S. Then OS is the radius for construction of the standard parallel.

On a separate sheet of paper draw a straight line which will be the central meridian of the projection and mark O' and S' on it so that $O'S' = OS$ (just obtained). With centre O' and radius OS, describe an arc to represent the standard parallel (see Fig. 150).

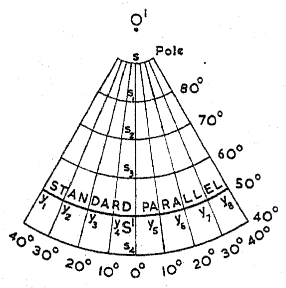


Fig. 150. PART OF THE NETWORK OF A SIMPLE CONICAL PROJECTION WITH ONE STANDARD PARALLEL.

$O'S' = OS$ (Fig. 149); $S'y_5 = y_5y_6$, etc., $= SY_2$ (Fig. 149); $ss_1 = s_1s_2$, etc., $= 2\pi R/36$.

The remaining parallels are spaced their correct distance apart, *i.e.* $\frac{n}{360} \times 2\pi R$, where n is their number of degrees apart and R the radius of the globe at the scale used.

Along $O'S'$ and $O'S'$ produced beyond S', mark off distances $S's_3$, s_3s_2, $S's_4$, etc., equal to $\frac{n}{360} \times 2\pi R$.

With centre O' and radius Os, Os_1, etc., describe arcs to represent the remaining parallels.

Return to the construction figure in which YS is the radius of the standard parallel. Thus the quadrant YSY_1, centre Y, radius YS, represents, although not in the correct plane, a quarter of this parallel, latitude ϕ. Therefore, the arc subtended along YSY_1 by an angle of 10° is equal to the length of 10° of longitude in latitude ϕ, and thus is the correct spacing in latitude ϕ for meridians 10° apart in the projection.

Mark $\angle SYY_2 = 10°$, then the arc YY_2 represents this distance.

On the graticule already constructed, mark off along the standard parallel distances $S'y_5$, y_5y_6, $S'y_4$, y_4y_3, etc., equal to SY_2. Draw in the remaining meridians as straight lines, joining each of these points y_1, y_2, y_3, etc., with O'. Since the pole is an arc through s, however, meridians will not pass through O' but stop at this arc (see Fig. 150).

Trigonometrical Method.—(See Fig. 149.)

In $\triangle OCS$, $\angle OCS = 90° - \phi$, $\angle OSC = 90°$;

$$\therefore \ OS = CS \tan (90° - \phi)$$
$$= R \cot \phi.$$

This formula gives the radius for the standard parallel.

Spacing for the remaining parallels $n°$ apart is given by $\frac{n}{360} \times 2\pi R$ (as above).

The radius, on the globe, of the standard parallel is $R \cos \phi$;[1]

$\therefore$ the length of the standard parallel is $2\pi R \cos \phi$;

$\therefore$ the spacing of the meridians $d°$ apart along the standard parallel is given by $\frac{d}{360} \times 2\pi R \cos \phi$.

For the remaining details of construction, see above.

2. THE CONIC SECANT PROJECTION.—In this projection the cone is imagined as sunk into or cutting the sphere along two parallels, which are thus standard parallels. This does not give a good practical projection but a development from it is—

3. THE SIMPLE CONICAL PROJECTION WITH TWO STANDARD PARALLELS in which, although two parallels are made their correct length to scale, their distance apart is also correct, as it would not be in the conic secant projection. The cone, however, in this case, must be regarded as quite independent of the globe, and in no way touching or cutting it.

The projection is neither equal area, nor orthomorphic, but the distortion of scale and shape is less than in the simple conical projection with one standard parallel and is distributed more evenly over the map. Meridian scale is everywhere correct and parallel scale is correct along both standard parallels. Meridians are straight lines and cross the parallels at right angles.

The projection is frequently used in atlas maps of European countries, the standard parallels being chosen approximately one-sixth of the distance from the top and bottom of the map. It is also sometimes used for larger countries, which have a greater latitude than longitude, such as the U.S.A. It is not very suitable for such large areas, however.

[1] See, *e.g.* Fig. 149. In $\triangle YCS$, $\angle YSC = \phi$, $SC = R$, $\angle SYC = 90°$; $\therefore$ $YS = R \cos \phi$.

Construction.—Make a construction figure similar to Fig. 151. In this figure BC is a straight line equal in length to the distance between the two standard parallels at the required scale for the projection, *i.e.* $BC = \frac{m}{360} \times 2\pi R$, where m is the number of degrees between the standard parallels and R is the radius of the globe at the scale required.

MB and NC are perpendicular to BC at B and C respectively, and are equal in length to the radii of the two standard parallels.

These radii may be found by drawing a further construction figure similar to Fig. 152. In this figure the semicircle $E'NE$ represents the Northern hemisphere in section at the required scale for the projection, with N and C the north pole and centre respectively, and $E'E$ the equator.

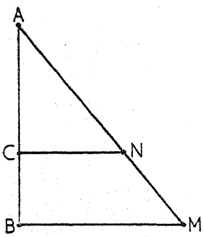


Fig. 151. $BC = 2\pi R \times \frac{m}{360}$; $BM = S_1Y$ (Fig. 152); $CN = S_2Z$ (Fig. 152).

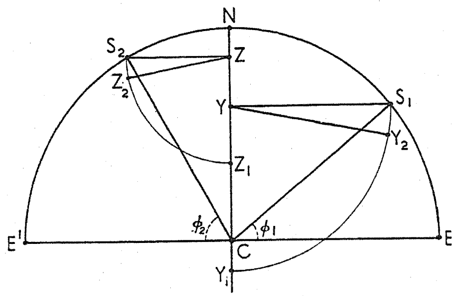


Fig. 152.

S_1 and S_2 are points of latitude ϕ_1 and ϕ_2, where ϕ_1 is the latitude of the lower standard parallel, and ϕ_2 is the latitude of the higher standard parallel.

From S_1 and S_2 respectively, draw S_1Y and S_2Z perpendicular to CN. Then these are the radii on the globe of the two standard parallels, and BM (Fig. 151) $= S_1Y$ and CN (Fig. 151) $= S_2Z$.

Now join MN and produce it to cut BC produced in A. Then AB and AC are the radii with which to describe the standard parallels on the projection.

On a separate sheet of paper, draw a straight line which will be the central meridian on the projection and mark on it A', B', and C' so that $A'C' = AC$ (just obtained) and $A'B' = AB$ (see Fig. 153).

With centre A' and radius AC, describe an arc for the higher standard parallel.

With centre A' and radius AB, describe an arc for the lower standard parallel. The remaining parallels are spaced their correct distance apart, *i.e.* $\frac{n}{360} \times 2\pi R$, where n is their number of degrees apart.

Along $A'B'$ and $A'B'$ produced beyond B', mark off distances $B'b_3$, $C'b_2$, $B'b_4$, etc., equal to $\frac{n}{360} \times 2\pi R$.

With centre A' and radius $A'b$, $A'b_1$, etc., describe arcs for the remaining parallels (see Fig. 153).

Return to the construction figure (Fig. 152). With centre Y and radius YS_1, describe a quarter circle Y_1S_1 which represents, although not in the correct plane, a quarter of the small circle latitude ϕ_1, at the scale used, and the arc subtended along it by 10° is equal to the length of 10° of longitude in latitude ϕ_1.

Mark $\angle S_1YY_2 = 10°$, then the arc S_1Y_2 represents this distance.

Similarly, the arc S_2Z_2 represents the length of 10° of longitude in latitude ϕ_2.

Return to the projection network already drawn and mark off along the two standard parallels points as y_1, y_2, etc., and z_1, z_2, etc., so that $B'y_4 = y_4y_3 = B'y_5 = y_5y_6$, etc., $= S_1Y_2$ (just obtained) and $C'z_4 = z_4z_3 = C'z_5 = z_5z_6$, etc., $= S_2Z_2$ (just obtained).

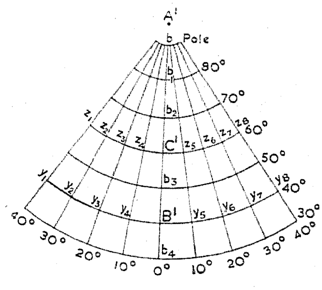


Fig. 153. PART OF THE NETWORK OF A SIMPLE CONICAL PROJECTION WITH TWO STANDARD PARALLELS.

A′C′ = AC (Fig. 151); A′B′ = AB (Fig. 151); $C'z_5 = z_5z_6$, etc., $= S_2Z_2$ (Fig. 152); $B'y_5 = y_5y_6$, etc., $= S_1Y_2$ (Fig. 152); $bb_1 = b_1b_2$, etc., $= 2\pi R/36$.

Join y_1z_1, y_2z_2, etc., and produce them to the arc through b which represents the pole, and to the lower limit of the projection network.

Trigonometrical Method.—In Fig. 151 (for explanation see above).

$BM = R \cos \phi_1$, where ϕ_1 is the latitude of the lower standard parallel.[1]

$CN = R \cos \phi_2$, where ϕ_2 is the latitude of the higher standard parallel.

$BC = \frac{2\pi Rm}{360}$ (see above).

$\triangle$'s ACN and ABM are similar ($CN \parallel BM$ by construction);

$$\therefore \frac{AB}{AB - AC} = \frac{BM}{BM - CN}.$$

[1] See footnote on p. 233.

$$AB = \frac{BM \times BC}{BM - CN}$$
$$= \frac{R \cos \phi_1}{R (\cos \phi_1 - \cos \phi_2)} \times \frac{2\pi Rm}{360}$$
$$= \frac{\cos \phi_1}{\cos \phi_1 - \cos \phi_2} \times \frac{2\pi Rm}{360}.$$

And $$AC = AB - BC = AB - \frac{2\pi Rm}{360}.$$

These formulae give the radii for the two standard parallels, spacing for the other parallels $n°$ apart is given by $\frac{2\pi Rn}{360}$ (as above).

The length of the lower standard parallel is $2\pi R \cos \phi_1$;

$\therefore$ spacing along it of the meridians $d°$ apart is given by $\frac{2\pi Rd \cos \phi_1}{360}$.

Similarly, the spacing of the meridians along the higher standard parallel is given by $\frac{2\pi Rd \cos \phi_2}{360}$.

For the remaining details of construction see above.

4. MODIFIED CONICAL PROJECTIONS

Although the simple conical projections are easy to construct and give quite good general projections, far better ones can be made by slight mathematical alteration. The network so produced is not the developed surface of a cone, but a drawn network of arcs and curves variously constructed.

1. BONNE'S PROJECTION is the simplest of the modified conical projections and is one of the most commonly used atlas projections. In it, the central meridian and parallels are drawn exactly as in the simple conical projection with one standard parallel, but true meridian distances are marked along each parallel and the remaining meridians inserted by joining the points so obtained. Thus, parallel scale is everywhere correct and the pole is a point. Since parallels and meridians are both correctly spaced, the projection is an equal area one, but the meridians, except the central one, are curves and are too long; they do not cut the parallels at right angles, and the projection is not orthomorphic. Distortion of shape increases away from the centre of the map, but the projection is suitable for maps, especially distribution

maps, of most countries, and even for areas as large as Western Europe as a whole. It is frequently used for larger areas, such as Asia, however, although it is not well suited to such a use. In such cases shape distortion is considerable near the corners of the map, although the equal area property is, of course, everywhere retained.

Construction.—The central meridian (*PC*, Fig. 154) and all the parallels, of which *MQN* is here the standard parallel, are drawn exactly as for the simple conical projection with one standard parallel (see p. 235).

On each parallel so drawn, mark off the correct meridian distances[1] (e.g. aa', Qq', Fig. 154) which can be obtained by an extension of the graphical method explained for the two standard parallels on p. 236 (see Fig. 152), or as $\frac{d}{360} \times 2\pi R \cos \phi$, where ϕ is the latitude of the parallel in question and d is the number of degrees apart of the meridians.

Join the corresponding points so obtained (e.g. a', q', b', c', d') by smooth curves to give the meridians.

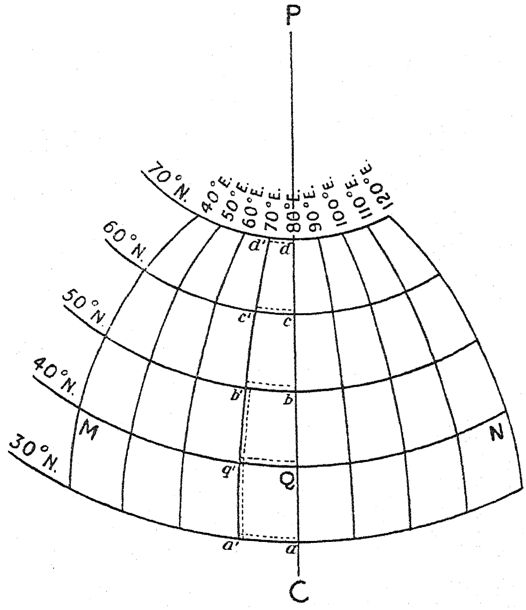


Fig. 154. BONNE'S PROJECTION.

2. THE POLYCONIC PROJECTION.—In this projection, each parallel is drawn as a standard parallel with its own centre and radius, almost as though a separate cone touched the globe for each parallel. The parallels are their correct length and their correct distance apart along the central meridian. Meridians are smooth curves, their correct distance apart along each parallel, but are too long and since the arcs representing the parallels are not concentric, distances between the parallels are also too

[1] *I.e.* the distances between adjacent meridians.

great except along the central meridian. Meridians and parallels do not cut at right angles and the projection is neither equal area nor orthomorphic. Distortion is not great, however, and the projection is much favoured in

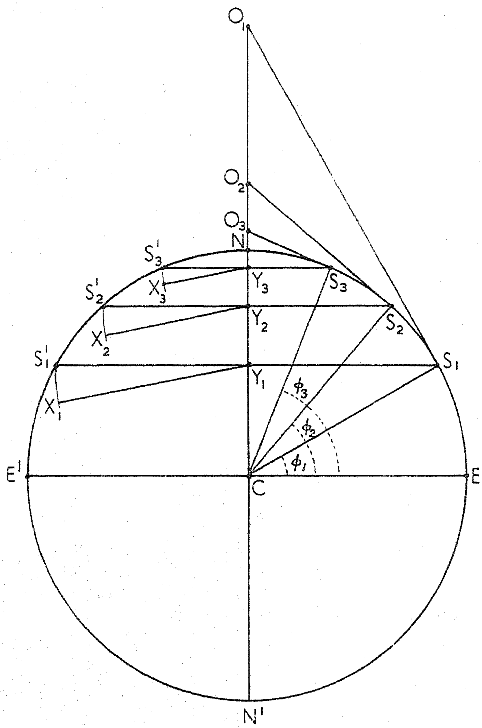


Fig. 155. To Obtain the Radii for the Description of the Parallels, and the Meridian Distances, on the Polyconic Projection.

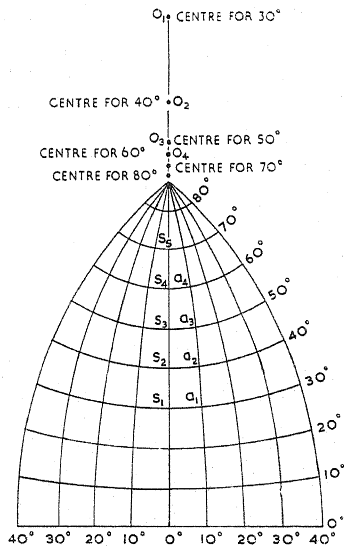


Fig. 156. Part of the Network of the Polyconic Projection.

American atlases for maps of countries which, in this country, would more often be plotted on Bonne's projection.

Construction.—Make a construction figure similar to Fig. 155. In this figure, the circle *E'NEN'* represents the globe in section at the required scale for the projection with *N*, *N'*, and *C* the north and south poles and centre respectively.

Draw in EE', S_1S_1', S_2S_2', S_3S_3', etc., the diameters of the equator, and the lines of latitude ϕ_1, ϕ_2, ϕ_3, etc., respectively, by making EC, S_1Y_1, S_2Y_2, S_3Y_3, etc., perpendicular to CN.

Draw S_1O_1, the tangent to the globe at S_1, and produce it to O_1, a point on $N'N$ produced. Then O_1S_1 is the radius for description of the parallel latitude ϕ_1 on the projection.

Similarly, O_2S_2, the tangent at S_2, is the radius for description of the parallel latitude ϕ_2 and O_3S_3, the tangent at S_3, is the radius for description of the parallel latitude ϕ_3, etc.

On a separate sheet of paper (see Fig. 156) draw a straight line, which will be the central meridian, and mark on it o_1 and s_1 so that $o_1s_1 = O_1S_1$ (Fig. 155).

The parallels are correctly spaced along the central meridian and therefore the distance between them is $\frac{2\pi Rn}{360}$, where n is their number of degrees apart, and R the radius of the globe at the scale used.

On o_1s_1 mark s_2, s_3, etc., so that

$$s_1s_2 = s_2s_3, \text{ etc.}, = \frac{2\pi Rn}{360}.$$

From s_2 mark s_2o_2 along o_1s_1 so that

$$s_2o_2 = S_2O_2.$$

Similarly, mark in o_3, etc., so that

$$s_3o_3 = S_3O_3, \text{ etc.}$$

Then o_1, o_2, o_3, etc., are the centres for the description of the parallels, latitudes ϕ_1, ϕ_2, ϕ_3, etc.

With centre o_1 and radius o_1s_1, draw the parallel for latitude ϕ_1; with centre o_2 and radius o_2s_2, draw the parallel for latitude ϕ_2, etc.

Return to the construction figure. With centre Y_1 and radius Y_1S_1', draw an arc through S_1'. Then this arc represents, although not in the correct plane, part of the parallel latitude ϕ_1 at the scale used, since Y_1S_1' is the radius of this parallel. The arc subtended along it by 10° is equal to the length of 10° of longitude in latitude ϕ_1. Mark $\angle S_1'Y_1X_1 = 10°$, then the arc $S_1'X_1$ represents this distance.

Similarly, the arc $S_2'X_2$ represents the length of 10° of longitude in latitude ϕ_2, and the arc $S_3'X_3$ represents a similar meridian distance in latitude ϕ_3, etc.

Return to the projection network and along each parallel set off true meridian distances. Along the parallel through s_1 these will equal $S_1'X_1$, along that through s_2, $S_2'X_2$, etc. Join the corresponding points (e.g. $a_1a_2a_3$, etc.) to give the remaining meridians.

The pole is a point on this projection and the equator a straight line perpendicular to the central meridian.

Trigonometrical Method.—See Fig. 155 which is explained above.

In $\triangle\ O_1S_1C$, $\angle\ O_1CS_1 = 90° - \phi_1$, $\angle\ CS_1O_1 = 90°$, $CS_1 = R$, where R is the radius of the globe at the scale used;

$$\therefore\ O_1S_1 = R \cot \phi_1.$$

Similarly, $$O_2S_2 = R \cot \phi_2.$$

To draw the central meridian and the parallels, proceed as above but use the distances thus calculated in place of measured distances for $o_1s_1 = O_1S_1$, $o_2s_2 = O_2S_2$, etc.

The meridian distances along each parallel are given by $\frac{d}{360} \times 2\pi R \cos \phi$, where d is the number of degrees between meridians; thus meridian distances along the parallel through s_1 will be $\frac{d}{360} \times 2\pi R \cos \phi_1$, along that through s_2, $\frac{d}{360} \times 2\pi R \cos \phi_2$, etc.

Draw in the meridians as above.

The One-in-a-million International Map is drawn on a modified form of the polyconic projection. Unlike the latter, in which meridians are curves, the International meridians are straight lines. As in the polyconic, the parallels are arcs of circles but not concentric.

Each sheet of the International map is plotted separately on its own central meridian, a straight line at right angles to the parallels. The boundary north and south parallels are plotted with radii derived from tables (and the same as they would be in a true polyconic projection). These parallels are divided truly, according to scale, as in the polyconic projection, but the remaining meridians are drawn by joining corresponding points on the north and south parallels with straight lines.

Combination of Sheets in 1/M International Map.—Fig. 157*a* shows that a sheet of this map will fit any one of its four surrounding sheets, but if further sheets are added, fit cannot be obtained in all directions. Figs. 157*b*

and 157*c* show two ways of distributing the misfit. Further combination is possible, *e.g.* in Fig. 157*b*; other sheets could be added to 2 and 4, and to 3 and 5 in Fig. 157*c*.

Each sheet covers an area of 4° of latitude and 6° of longitude, and though more than nine sheets do not fit well, it is possible to build up a map of large area without noticeable gaps.

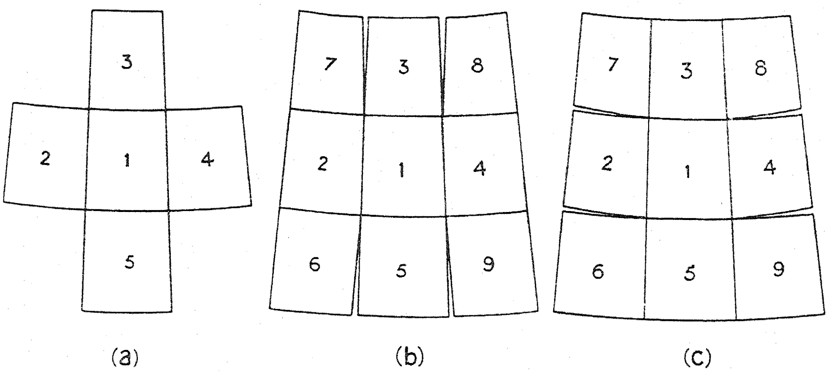


Fig. 157.

CHAPTER XIX

MAP PROJECTIONS: III—CYLINDRICALS, CONVENTIONAL PROJECTIONS; CHOICE OF PROJECTIONS

I. CYLINDRICAL PROJECTIONS

In these projections the surface of the globe is imagined drawn on to a cylinder which can then be unrolled. The cylinder may touch the globe along any great circle, whether the equator, a meridian, or neither, but the most usual case is that in which it touches along the equator.

1. THE CYLINDRICAL EQUAL AREA PROJECTION.—In this projection all meridians and parallels are straight lines cutting at right angles, and the meridians are their correct distance apart at the equator. The parallels are spaced so that the area contained between them on the cylinder is equal to the curved area contained between the same parallels on the globe. In order to retain the equal area property, shapes are badly distorted in high latitudes, and the poles are straight lines, the same length as the equator. The projection is extremely simple to construct, however, and is well suited to mapping the distribution of tropical crops and diseases.

Construction.—Make a construction figure similar to the left-hand side of Fig. 158. In this figure, the circle *WNES* represents the globe in section at the required scale for the projection, and *ABCD* is the circumscribing cylinder of the same height, on to which the projection is made. *N*, *S*, and *O* are the north and south poles and centre respectively and *WE* is the equator. m and p are points of latitude ϕ_1 and ϕ_2 N., and m' and p' are points of latitude ϕ_1 and ϕ_2 S. *mxr* and *pyq* are the diameters of parallels latitudes ϕ_1 and ϕ_2 respectively.

The surface area of the zone of the globe *EmrW* is equal to the surface area of the cylindrical section *EadW*.[1]

Thus the parallel through m will be represented on the projection by a straight line, distance *Ea* from the equator.

[1] For proof of this statement, students are referred to mathematical textbooks.

Similarly, the parallel through p will be represented by a straight line, distance Eb from the equator.

The projection may be drawn next to the construction figure as in Fig. 158. Draw the parallels as straight lines, parallel with WE, passing through N, p, m, E, m', p', and S.

Along the equator mark off the correct meridian distances given by $\frac{2\pi Rn}{360}$, where n is the number of degrees between meridians, and draw in the meridians as straight lines through these points, perpendicular to the parallels.

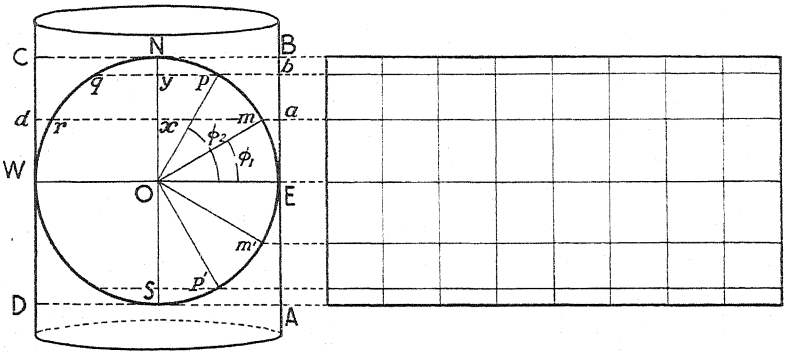


Fig. 158. CYLINDRICAL EQUAL AREA PROJECTION.

Trigonometrical Method.—The spacing of the parallels may be obtained as follows:

In Fig. 158 the distance of the projected parallel latitude ϕ_1 from the equator $= Ea = Ox$ ($mx \parallel EO$ by construction)

and $\qquad \angle Omx = \phi_1 \; (mx \parallel EO)$.

In $\triangle\, Omx$, $Ox = Om \sin \phi_1 = R \sin \phi_1$, where R is the radius of the globe at the scale used.

Similarly, $\qquad Oy = R \sin \phi_2$.

And $\qquad ON = R$.

The parallel latitude ϕ_1 S will be $R \sin \phi_1$ south of the equator, etc., in the projection.

Meridians are spaced and drawn as above.

2. MERCATOR'S PROJECTION.—A much used and well-known cylindrical projection is that of Mercator, which dates as far back as 1569. The meridians are equidistant vertical straight lines correctly spaced in 0°. Parallels are horizontal straight lines. They are not equidistant, but to preserve the correct ratio between degrees of latitude and longitude, their distances apart are increased as the latitude increases. The construction of Mercator's projection involves mathematics or recourse to tables prepared

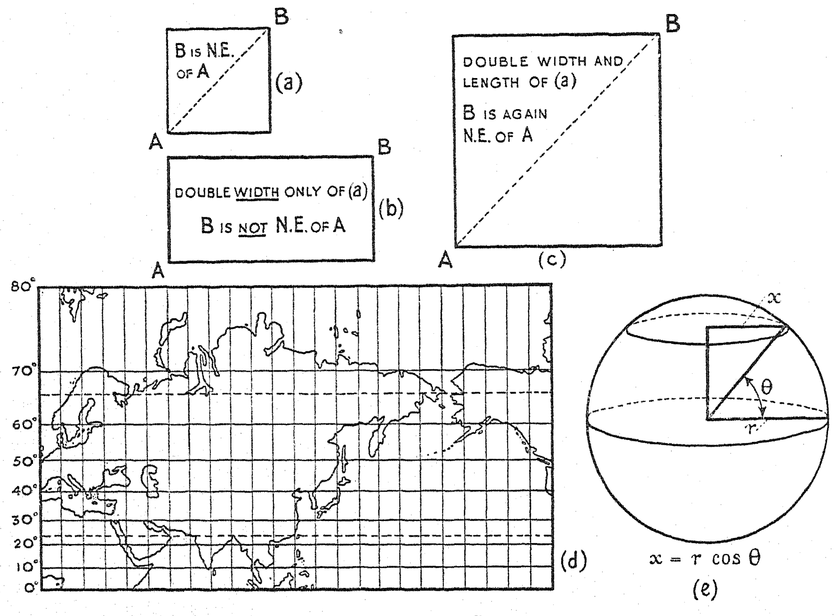


Fig. 159. MERCATOR'S PROJECTION.

for the purpose, but the following will convey some idea of the general principle.

Assuming the earth to be a perfect sphere, the radius of the (small) circle round the globe representing, say, latitude 45°, is equal to the radius of the (great) circle representing the equator, multiplied by cos 45° (*i.e.* multiplied by $\frac{1}{\sqrt{2}}$ — Fig. 159*e*). The length of a degree of longitude at the equator is therefore $\sqrt{2}$, or 1·414 times that of a degree of longitude at

latitude 45°. In Mercator the length of a degree of longitude at latitude 45° is made equal to that of a degree at the equator, for the longitudinal lines are parallel lines. Thus the length of a degree of longitude at latitude 45° is increased $\sqrt{2}$ times, and therefore the length of a degree of latitude here must also be increased $\sqrt{2}$, or 1·414 times, to preserve the correct ratio (Fig. 159*a*, 159*b*, 159*c*). At latitude 60° the length of a degree of longitude is really only about half the length of a degree at the equator ($\cos 60° = \frac{1}{2}$): on Mercator the length is the same, so that the scale of longitude along the parallel of 60° is double the scale on the equator, and to preserve true proportions, the scale measured north and south must also be doubled (Fig. 159). Thus on Mercator the distance from latitude 60° to 61° is approximately twice as great as from latitude 0° to 1°, though on the globe these distances are equal. Similarly, it can be shown that at longitude 80° the length of a degree is increased 5·76 times (approximately), and so on. On this projection the shape of the land masses is approximately preserved, but area in high latitudes is much exaggerated. Alaska is shown nearly as large as the United States, though its area is only about one-fifth that of the States.

Bearings are everywhere correct on Mercator's projection and it is, therefore, almost always used for sailing charts and maps of routeways, where directions are important. It is also the official projection of the R.A.F. for aviation maps as, although the short great circle courses often flown are only plotted with difficulty on it, navigation by compass is simpler if bearings, rather than great circles, are represented by straight lines on the map.

Construction.—Draw the equator as a straight line and the meridians as a series of parallel straight lines, perpendicular to the equator and, here, their true distance apart ($= \frac{2\pi R}{36}$ where they are 10° apart, and R is the radius of the globe at the required scale for the projection).

Draw the parallels as straight lines parallel with the equator and at distances from it given by $\frac{2\pi R}{360} \times x$, where x is obtained from the following table and parallels are 10° apart.

Latitude	10°	20°	30°	40°	50°	60°	70°	80°
x	1·01	2·04	3·15	4·37	5·79	7·55	9·98	13·96

3. THE PLATE CARRÉE.—In this projection all meridians and parallels are straight lines at right angles to each other. The meridians are their correct distance apart at the equator and the parallels are everywhere their correct distance apart. The projection is neither equal area nor orthomorphic, but although it is almost never used, it forms the basis for a useful modification.

4. THE SINUSOIDAL OR SANSON-FLAMSTEED PROJECTION.—In this projection the parallels are drawn as in the plate carrée, but each is divided into its correct meridian distances from the central meridian, and the corresponding points so obtained are joined by curved lines which represent the

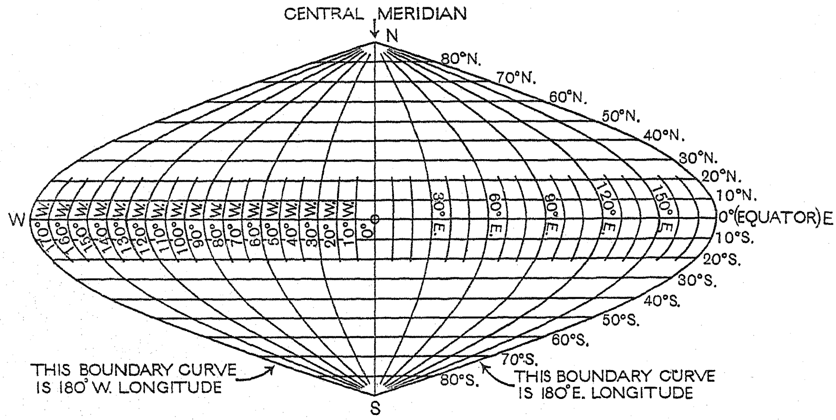


Fig. 160. SANSON-FLAMSTEED (SINUSOIDAL) PROJECTION.

remaining meridians. These meridians are too long but the distance apart of both parallels and meridians is correct, and thus the projection is an equal area one. The meridians and parallels do not cross at right angles, and the projection is not orthomorphic.

Although distortion of shape is considerable near the edges of the map, this projection may be used for world maps showing distributions, where the equal area property is desirable. There are few commodities which are produced mostly in the badly distorted high latitudes, but those which are, such as soft-wood timber, may better be shown on other projections, preferably the polar zenithal equal area projection (see p. 227).

The sinusoidal projection is even more suitable, however, for continents and countries which do not extend (1) too far north and south of the equator, or (2) too far east and west. Hence, by selecting the central meridian so that it passes through the centre of the continents, a useful graticule may be obtained for Africa or South America. If used for maps of Australia or North America there would be considerable distortion, however, because these continents have too much east to west extension away from the equator. For similar reasons, the projection is not suitable for Europe or Asia, which have their greatest east-west extent in high latitudes.

Construction.—Draw a horizontal straight line and mark W and E, so that $WE = 2\pi R$ (where R is the radius of the globe at the scale used). Then WE represents the equator (see Fig. 160).

Bisect WE at O and draw NOS perpendicular to WE at O so that $NO = OS = \frac{1}{2}\pi R$. NOS now represents the central meridian, whose total length is equal to half the circumference of the globe ($= \pi R$).

Divide NS into eighteen equal parts, each to represent 10° of latitude. (Each will be $\frac{2\pi R}{36}$ long.) Through each point of division draw a horizontal straight line to represent the parallels 10°, 20°, 30°, 40°, etc.

Now make a construction figure similar to the left-hand side of Fig. 155. The radius of the parallel latitude ϕ_1 will be $S_1'Y_1$ which can be measured. The length by which this parallel is represented on the sinusoidal projection will be $2\pi \times S_1'Y_1$, half of this distance being on either side of the central meridian. Therefore the distance on each side of the central meridian will be $S_1'Y_1 \times \pi$, which must be calculated.

Meridian distances for 10° along the parallel, latitude ϕ_1, can be obtained from the same figure by the method described on p. 239. Similarly for latitudes ϕ_2, ϕ_3, etc. It will probably be found more convenient, with parallels spaced every 10°, to draw two construction figures, one for latitudes 10°, 30°, 50°, and 70°, and the other for the remaining latitudes.

Return to the projection network already drawn, and mark off along each parallel the correct distances on either side of the central meridian and the meridian distances. Join corresponding points by smooth curves to obtain the remaining meridians (see Fig. 160).

Trigonometrical Method.—Draw the equator, parallels, and central meridian as above.

The length of any parallel, latitude ϕ, will be $2\pi R \cos \phi$, therefore the distance on either side of the central meridian will be $\pi R \cos \phi$.

Meridian distances for meridians 10° apart are given by $\frac{2\pi R \cos \phi}{36}$.

Complete the network as above.

2. CONVENTIONAL PROJECTIONS

So far, all the projections discussed have been based on the principle of transferring the meridians and parallels on to a developable surface;

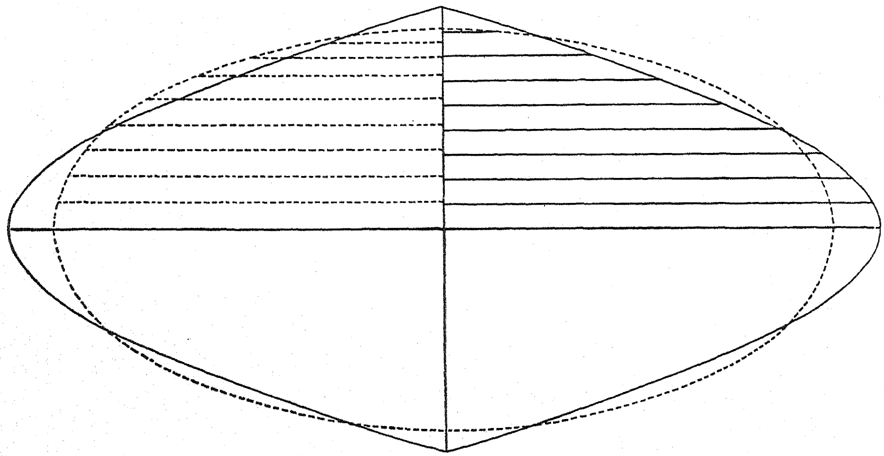


Fig. 161. Comparison of Mollweide and Sinusoidal Projections.

a plane in the zenithal projections; a cone in the conicals; and a cylinder in the cylindricals. The polyconic projection, Mercator's projection, and the sinusoidal projection, it is true, show little relation to the original cone or cylinder from which they were produced, but the idea of these shapes is behind that of the projections. In conventional projections, no attempt is made to project the parallels and meridians on to a given surface. The network is mathematically conceived from the outset. The most commonly used and easiest to understand of the now much favoured conventional projections is—

MOLLWEIDE'S PROJECTION.—In this projection the globe is represented by an ellipse of equal surface area, half of the globe's surface being contained within the centre circle of this ellipse. The meridians are ellipses except the central one which is a straight line. The parallels are drawn as straight lines parallel with the major axis of the ellipse, which represents the equator, and spaced so that the area contained between them is the same as the curved area contained between them on the globe. This spacing requires complicated calculation, and in practice it is obtained from specially constructed tables.

The parallels are straight lines, but the meridians are curves which do not cut them at right angles, and the projection is not orthomorphic. It is, however, equal area by construction, and is usually preferred to the sinusoidal for world distribution maps as the distortion of shape is rather less, and the form of the finished graticule is more pleasing to the eye. (See Fig. 161 for comparison of the two graticules.) It is also suitable for maps of the same countries and continents as the sinusoidal.

Construction.—First obtain the centre circle whose radius is r.

The surface area of the globe $= 4\pi R^2$, where R is the radius of the globe at the required scale for the projection;

$$\therefore \text{ the surface area of one hemisphere } = 2\pi R^2 = \pi.(2R^2).$$

The surface area of the centre circle $= 2\pi r^2$ but this must equal that of one hemisphere; $\therefore\ \pi r^2 = \pi.(2R^2)$;

$$\therefore\ r = \sqrt{2}.R.$$

With radius r (just calculated) and centre c, draw a circle represented by circle $aNbS$ in Fig. 162.

Draw acb which represents half the equator and produce it in each direction to W and E, so that $Wa = ac = cb = bE = \sqrt{2}R$. Then WE represents the whole equator.

Draw NS perpendicular to ab through c so that N and S lie on the circumference of the centre circle. Then N and S represent the north and south poles, respectively.

Calculate the distance of each parallel from the equator, at 20° intervals from the formula $x.R$, where x is given by the following table:

Latitude	20°	40°	60°	80°
x	0·385	0·751	1·077	1·336

Mark off these distances along the central meridian, and through each marked point draw a line parallel with the equator.

Calculate the length of each parallel from the formula $y.R$, where y is given by the following table:

Latitude	20°	40°	60°	80°
y	5·44	4·80	3·68	1·84

Mark off half this length on either side of the central meridian.

Divide *WE* into twelve equal parts, each to represent 30° of longitude. Similarly, divide each parallel. To represent meridians other than the

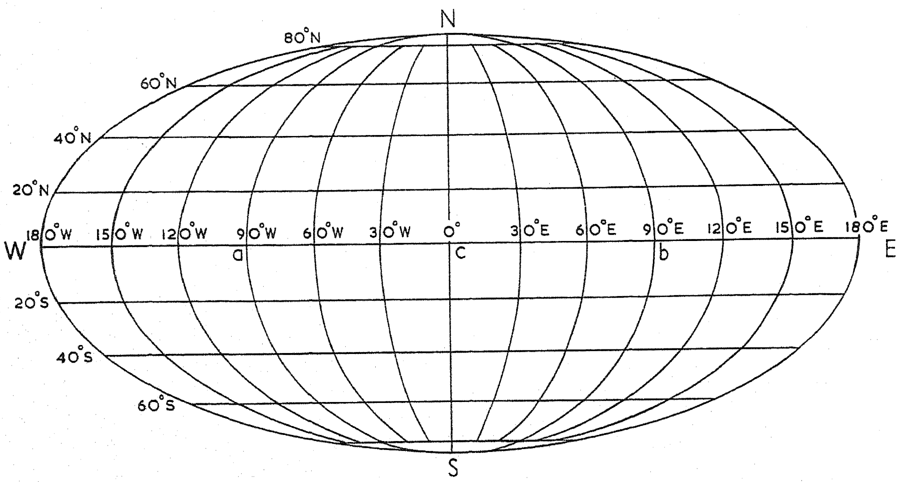


Fig. 162. Mollweide Equal Area Projection.

central meridian and that represented by the centre circle, draw elliptical curves joining the corresponding points so obtained, and the poles. To avoid overcrowding, the meridians should not be drawn nearer to the poles than 80° N. and S.

Mollweide's projection is usually drawn, as given above, with the equator as the major axis of the ellipse. Sometimes transverse and oblique projections with a different major axis are used, but for many atlas maps the process known as **interruption** is preferred.

In the INTERRUPTED MOLLWEIDE PROJECTION areas of special importance are noted, together with areas of negligible importance, each map being separately considered. Thus if a map is to show the distribution of world wheat production, the continents are important and the oceans not so, but if it is to show the distribution of fisheries, the reverse is true. The case of a continental distribution will be considered here.

Construction.—(See Fig. 163.) On this projection, distortion is least near the central meridian, thus each continent is drawn with its own central

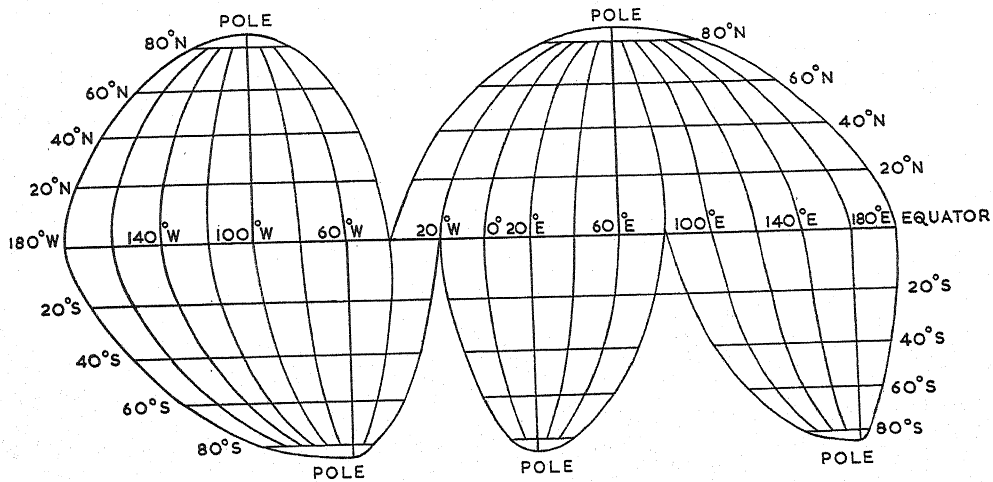


Fig. 163. THE INTERRUPTED MOLLWEIDE PROJECTION.

meridian. Select suitable central meridians for each continent, Eurasia being considered as one. Divisions have now to be made over the oceans so that the area of the map is still correct. Select suitable meridians for such division. It is not necessary to select the same meridians in both Northern and Southern hemispheres except in the case of the bounding meridian, here 180° E. and W.

Draw the equator as a horizontal straight line $4\sqrt{2}R$ in length (see p. 249) and divide it into eighteen equal parts. Each division represents 20° of longitude: label them carefully from 180° W.

At each point chosen for a continental meridian erect a perpendicular on the correct side of the equator, each perpendicular being $\sqrt{2}R$ long (see p. 249). These perpendiculars represent the central meridians here of 100° W. and 60° E. in the Northern hemisphere, and 60° W., 20° E., and 160° E. in the Southern. The free end of each perpendicular represents the pole for that part of the map of which it is the central meridian.

Mark carefully, at the equator, the meridians chosen for interruption of the map in each hemisphere. Here these are 40° W. in the Northern hemisphere and 20° W. and 80° E. in the Southern.

Calculate the distances of the parallels from the equator as above, mark off these distances along each central meridian. Draw the parallels as straight lines parallel with the equator through these points.

For each parallel, calculate the meridian distance for meridians 20° apart from $\frac{20}{360} \times yR$ (see p. 250 for y).

From each central meridian, mark off along each parallel, the number of meridian distances required in each direction thus:

For the Northern hemisphere: from 100° W., four divisions westward to 180° W., three divisions eastward to 40° W.; from 60° E., five divisions westward to 40° W., six divisions eastward to 180° E.

For the Southern hemisphere: from 60° W., six divisions westward to 180° W., two divisions eastward to 20° W.; from 20° E., two divisions westward to 20° W., three divisions eastward to 80° E.; from 160° E., four divisions westward to 80° E., one division eastward to 180° E.

Join corresponding points by smooth elliptical curves to give the meridians other than the central meridians. Those along which interruption occurs should be plotted on both sides of the break in each case (see Fig. 163).

3. CHOICE OF PROJECTIONS

When we select a projection for any map, there are several things to bear in mind. It is necessary to remember to what use the map is to be put, the position of the area to be mapped, and its extent with respect to latitude and longitude. Other things being equal, it is advisable to choose a projection reasonably easy to draw, and needing no abstruse mathematical calculation, since the properties of such a map are more readily apprehended by its users.

For *distributional maps* to show density of population or stock, distribution of cultivated crops or of natural vegetation, an equal area map is desirable, so that not only the actual distribution of the commodity can be noted, but also the relative size of the regions where it is found. Some projections show area fairly correctly to scale in certain latitudes, but distort it greatly in others.

For *a world map*, three well-known projections are the Cylindrical Equal Area, Mollweide, and Sanson-Flamsteed. No one of these is very difficult to draw. The first named is the easiest to draw, and for this reason would probably be selected for most purposes except for the fact that in high latitudes shape is much distorted, though the area is everywhere true to scale compared with the globe. There is little distortion between the tropics, so that it would be quite suitable for showing the distribution of products such as rice, rubber, or cane-sugar.

If the distribution of the *temperate* cereals, such as wheat or maize, is to be shown, the Cylindrical Equal Area would be less suitable, because the shape is much distorted where these crops are found. They are grown in large countries like the United States and the Argentine, and the shape of these should be preserved, for ease in reading if for nothing else. Hence Mollweide or Sanson-Flamsteed would be preferable, and the former would probably be the ultimate choice, most likely in its interrupted form.

For *equal area of a single country* or continent other projections are available, Bonne's being a favourite with atlas makers. It is least suitable for Asia, because this continent has too great extension through both longitude and latitude to avoid distortion in the north-west and north-east corners. For this purpose an oblique zenithal equal-area projection, touching the globe near the centre of the map, should be considered.

Maps for *small areas* such as the British Isles, the Baltic Lands, France, or the Balkan Peninsula, whether required for distributional purposes or to show ordinary physical features or political geography, would probably be on the Simple Conic with two standard parallels. This projection is easy to draw, and, if the standard parallels are wisely chosen, is reasonably correct as regards scale, preserves shape better than Bonne, but is not equal area, a point not of great importance for small areas with not too great extent of latitude. It is suitable for any extent of longitude, which, with

ease in drawing, would render it popular for maps of, say, the transcontinental railways like the Canadian Pacific and the Trans-Siberian.

For *maps of the polar regions* or of the tundras, one of the zenithals is best, possibly the Zenithal Equidistant, which shows distances along the meridians and bearings (azimuths) from the pole correctly.

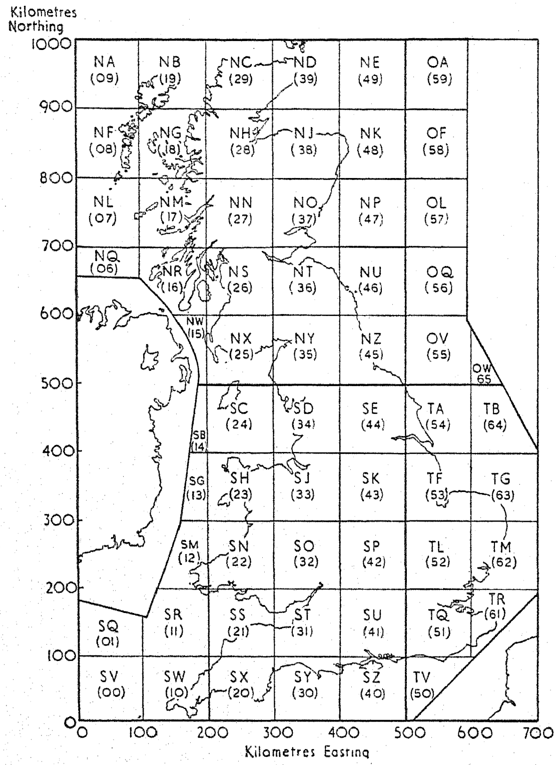


Fig. 164.

The usefulness of the Oblique and Equatorial Zenithals for *continents* and large countries may again be stressed.

Where correct representation of direction is desirable, for *navigation* on the sea or in the air, or to show the direction of ocean currents and planetary winds, Mercator is suitable. Distortion of area in high latitudes does not affect the main purpose for which the map would be used.

We have only mentioned some of the commonest projections. There are others less well known which for certain purposes may be very suitable, but which may be rather less easy to draw than those generally used by atlas makers.

Students should be able to recognise the various projections and to discuss their use for specific purposes. To do this some knowledge of the principles underlying their construction is necessary.

4. GRIDS

A grid is a combination of squares designed to facilitate reference to a map. It is not a graticule: latitude and longitude may be shown independently of the grid. All Ordnance maps to-day are drawn on the Transverse Mercator projection[1] and use the same grid reference system.

This National Grid consists of series of lines drawn parallel to and at right angles to the central meridian of the projection to form a number of squares each of sides 100 km. (Fig. 164). Within each of these squares further grid lines are drawn at 1 km. intervals and number 01 to 99. The reference of a point in a given 100 km. square, *e.g.* the railway station at Axbridge (map facing p. 138), can be obtained by writing down the numbers corresponding to the south-west corner of the 1 km. square containing it. The *easting* is 43 and the *northing* 54, so we get 4354 (note *easting* before *northing*). Remember that it is *always* the south-west corner that is used.

By eye estimation of tenths of a kilometre the reference could be given to within a tenth of a kilometre as 432547. Such a six-figure reference is known as a Normal National Grid Reference. Only if east-west or north-south distances greater than 100 km. appear on a map is it necessary to indicate *which* 100 km. square contains the given point. Originally this was done by prefixing the number of the 100 km. square, thus, 31/432547. Square 31 is the 100 km. square whose south-west corner is 300 ml. east and 100 ml. north of the origin of the grid (a point south-west of Land's End). Such an eight-figure reference was known as a Full National Grid Reference.

Unfortunately, in order to bring civil and military maps into line, the Ordnance Survey has found it necessary to modify this method by using letters instead of numbers to indicate 100 km. squares and the Full National Grid Reference of Axbridge Station is now written ST432547 (see Fig. 164).

EXERCISE IX

MAP PROJECTIONS

1. What would guide you in determining whether an atlas map of the world was on the Mercator or Mollweide projection?

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[1] The central meridian which is true to scale on this projection is 2° W., and positions of remaining meridians and parallels are calculated from formulae similar to those used for Mercator's projection.

2. Give instances in connection with world maps for which the Mercator and Mollweide projections would be (i) suitable; (ii) unsuitable, stating reasons.

3. Why might a Mercator map be fairly suitable for showing world distribution of rice or rubber but not of wheat? Suggest, giving your reasons, a better projection for rice or rubber distribution.

4. How would you recognise a zenithal projection from a general inspection? Name some of the chief zenithal projections and give their main characteristics.

5. For what types of map might some of the better-known zenithal projections be used? Mention briefly some of the limitations of this class of projection.

6. Which would you prefer for a world map to show relief features: the Sanson-Flamsteed (sinusoidal) or Mollweide projection? Give reasons.

7. Point out the usefulness of the following projections for specific purposes: Bonne, Simple Conical with one standard parallel, Conical with two standard parallels.

8. What projections would you use for Africa and South America (i) to emphasise orthomorphism, *i.e.* correct shape; (ii) to show distribution of rubber, cotton, and wheat? Give reasons for your choice.

9. What projections would you select to show (i) route of the Canadian Pacific Railway; (ii) the Mississippi basin; (iii) prevailing winds and ocean currents of the Atlantic and Pacific Oceans? Give reasons.

10. Say why you consider the following projections would be unsuitable, viz. (i) Mercator for Canada, (ii) Sanson-Flamsteed for Australia, (iii) Bonne for Eurasia (*i.e.* Europe plus Asia), (iv) the Simple Conic with one standard parallel for South America.

11. Compare and contrast the properties of Conical and Cylindrical projections. Mention, giving your reasons, one region for which each is, and is not, suitable.

General Atlas Maps

1. In connection with atlas maps, mention the contour intervals you have seen used for maps of (1) the world; (2) a continent like Africa or South America; (3) England and Wales; (4) France; (5) Switzerland; (6) India.

In each case suggest the type of features which the contours are designed to show. In what way do the relief features of these maps differ from those of large-scale topographical maps?

2. What do you understand by (i) a physical or physiographical region; (ii) a climatic region; (iii) a natural region? To what extent would your ordinary atlas maps be useful in determining such regions for (i) a given country; (ii) a continent?

3. To what extent do you consider that a small-scale atlas map gives an erroneous or a limited impression of the relief of a continent? In this respect compare an atlas map of North America with the topographical maps on a scale of 1 : 50,000 for, say, the western highlands in Oregon and Washington.

4. In connection with any atlases with which you are familiar mention what material it contains which will help you to—

(i) Explain the distribution of population in England and Wales;

(ii) Suggest broad climatic regions for a continent like North or South America.

5. Compare the ordinary climatic maps of a good school atlas with the weather maps issued by the Meteorological Office. Bring out differences as regards content and symbols used, and suggest for what particular purpose each type of map is intended.

6. How would you use reasonably good atlas maps to help you in describing the connection between physical features and routes in Switzerland and France? Which do you consider the more directly useful for this purpose and why?

EXERCISE X

Some Further Questions (*Mainly on Part I*)

1. Draw contoured sketches to show a cirque, a drumlin area, a basin of inland drainage in an arid climate, and add brief notes to explain their typical features.

2. Draw contoured sketches to show the difference between the drainage of a chalk plateau of fairly uniform height and that of a clay vale adjacent to the plateau scarp. Add brief explanatory notes.

3. Draw contoured sketches to show the characteristics of a fjord coast and of the adjacent country, where there may be ribbon lakes which further sinking of the land would transform into fjords. Mark the sites of possible settlements and give reasons for the same.

4. Draw contoured sketches to show the sites of probable human settlements—
   (i) Around an estuary which cuts through a range of chalk hills, but which is mostly surrounded by lowland;
   (ii) In chalk uplands, the scarp side of which is fretted by the headwaters of small streams, there being several well-developed valleys on the gentler anti-scarp slope.

5. Draw contoured sketches to show the relief features and drainage of a formerly glaciated area and add brief explanatory notes where desirable.

6. Write a short essay describing and criticising the methods of showing relief on (i) topographical; (ii) atlas maps. Refer to concrete examples when possible.

7. To what extent is the practical surveyor concerned in the representation of relief referred to in the last question? What instruments would he probably use and for what specific purpose?

8. What is meant by the cartographical characteristics of a map? Illustrate by reference to the latest edition of the English 1 : 63,360, or the French 1 : 50,000 official maps.

9. Similarly treat the International 1 : 1,000,000 map.

10. Compare, from the standpoint of cartographical methods employed and the practical usefulness of such methods, the "Tourist" maps and the ordinary New Popular Edition sheets of the 1-in. Ordnance Survey map.

11. Compare the cartographical methods used on the 1-in. map (Relief Edition) and 6-in. Ordnance Survey plan.

12. What do you understand by "hydrographical" features? Illustrate by reference to any topographical maps contained in this book, and briefly describe such features.

13. Explain, with illustrative sketches, how you would represent by diagrammatic or cartographical methods—

(a) Variability of rainfall and temperature for a certain station for a period of twenty years;

(b) Variability of population for a town and for a county as indicated by the figures for two separate census years.

Point out any special difficulties in connection with the use and adjustment of the available data, and say how you would overcome them.

Note.—(a) and (b) above can be regarded as separate questions.

14. What data would you need to make a rainfall map of, say, England north of the Mersey and Humber? Given this data, explain how you would produce such a map. Note its limitations.

HINTS FOR FURTHER READING AND STUDY

Candidates for the degree examinations of London University and others requiring more advanced preparation, are referred to the following books:

Map Work, by V. S. Bryant and T. H. Hughes. A good general treatment of the practical methods necessary in map making, with hints for map reading and military sketching.

Maps and Survey, by A. R. Hinks. A standard and scholarly, but not too difficult, treatment of the study of maps and the processes of survey by which they are made. A very helpful book, especially when used in conjunction with some representative sheets of the various British and foreign official maps referred to in the chapters on map analysis.

Maps: Topographical and Statistical, by T. W. Birch. Treats the history, construction, and use of maps in a detailed, scholarly, and practical outlook. As the Preface says, "The object of the first part of this book, which includes information about maps past and present, land and air-photo survey, and map projection, is to contribute to an understanding of topographical maps, map-reading, and the interpretation of landscape as recorded on maps. The second part of the book deals with statistical maps and diagrams, and particularly with the problems involved in their preparation." A good advanced textbook and work of reference. The Bibliography is practical and comprehensive.

The official *Text Book of Topographical and Geographical Surveying*, by Sir Charles Arden Close and Brigadier H. S. L. Winterbotham. The standard work of its kind. Surveying methods required for the production of large-scale topographical maps are described in considerable detail. Throughout, there is careful correlation between surveying and the map. Much useful information is given about projections and maps. An indispensable reference book for more advanced students.

Mathematical Geography, two volumes, by A. H. Jameson and M. T. M. Ormsby. Volume I deals with elementary surveying and map projections; Volume II with simple astronomical and trigonometric surveying, and the more advanced study of map projections. Founded on lecture notes of

courses given to internal students of London University, these volumes are very helpful and very practical.

General Cartography, by Raisz, and *Maps and Diagrams: Their Compilation and Construction*, by Monkhouse and Wilkinson, are two very good recent books on maps and diagrams; the former being an American book, gives notes on American maps rather than British ones, but is very valuable for work on statistical maps and diagrams and gives several original methods of representing data graphically. *Maps and Diagrams* also gives good material in this field and has some good notes on the preparation and use of block diagrams.

Land Forms and Life, by C. C. Carter. Largely an analysis of typical 1-in. British Ordnance Survey maps and a few similar foreign maps. In each case the physical features are examined in sufficient detail to explain settlement and other aspects of human geography. Very useful for the interpretation of topographical maps. It is desirable to use as many as possible of the typical map sheets referred to in the book.

Map and Landscape, by Dorothy Sylvester, gives excellent notes on the interpretation of Ordnance Survey maps, both in the laboratory and in the field, and on the application of these methods to regional survey.

Ordnance Survey Maps; their Meaning and Use, by M. I. Newbigin. Brings out the physical characteristics of typical regions like the Western Grampians, and is characterised by sound geographical scholarship.

The Geographical Interpretation of Topographical Maps, by A. Garnett. A useful help to map reading, especially in correlating such maps with human geography.

The Map of England, by Sir Charles Close. Contains much useful practical information about Ordnance maps and is very helpful in map reading.

Map Making, by Professor F. Debenham. Very useful for surveying methods. Contains statistical results of various types of survey; deals with their entry, use, and, if necessary, their adjustment. Contains a very useful chapter on the making and adaptation of simple instruments.

Exercises in Cartography, by Professor F. Debenham. Practical work as done by first-year students in the Department of Geography, Cambridge

University. The actual exercises are accompanied by clearly-written chapters on various aspects of cartography. The chapters on relief models and block diagrams are particularly interesting apart from their academic value.

The Weather Map, a standard Meteorological Office publication. Indispensable for understanding all about the preparation and interpretation of weather maps. The *Daily Weather Reports* of the Meteorological Office should be carefully studied and comparisons of typical weather maps made as these are issued.

Meteorology for Aviators, by Dr R. C. Sutcliffe, and *Weather Study*, by Professor David Brunt, deal with the most recent methods of weather study and forecasting.

Map Projections, by A. R. Hinks. A standard textbook written by a geographer for geographers. It is indispensable for advanced students.

An Introduction to the Study of Map Projections, by Professor J. A. Steers. Endeavours to minimise the mathematical difficulties associated by some students with map projections. Is very good for graphical methods requiring a minimum of mathematics. This lucid and inspiring book can be strongly recommended.

Introduction to the Mathematics of Map Projections, by R. K. Melluish. Deals with the mathematical aspect of the subject and will be of interest to advanced students.

Geological Maps; their Interpretation and Use, by A. R. Dwerryhouse.

Geological Maps; the Determination of Structural Detail, by R. M. Chalmers.

The Study of Geological Maps, by G. E. Elles.

The first two books deal with the interpretation of geological maps, largely with a view to understanding the preparation of geological sections. The third stresses the interpretation of geological maps in relation to topographical maps. Whatever book is used, there is need for careful study of typical geological maps.

The Elements of Field Geology, by G. W. Himus and G. S. Sweeting. A very useful book which will enable the student to make a practical

geological examination of a given area. Clear and practical diagrams are a feature of this book.

Stanford's Geological Atlas of Great Britain and Ireland. Very useful for its maps and for the wealth of explanatory detail.

O.S. Agricultural Atlas of England and Wales. Many distributional maps constructed according to the dot method and based on county statistics.

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